

**PALEOGEOGRAPHY
OF
SOUTH AMERICA**

by

LEWIS G. WEEKS

and

HORACIO J. HARRINGTON



COMPILED BY STALYN PAUCAR

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OF
SOUTH AMERICA¹**

by

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ABSTRACT

The major features of the geologic framework of the continent are outlined. Attention is called throughout the paper to the many similarities in the continental framework and geologic history of South America with those of North America.

The change in paleogeography and facies from Cambrian to Pliocene inclusive is pictured on 15 paleogeographic facies maps selected to show the principal sedimentary overlaps. Intervening changes and conditions, the progress of transgressions, and the fundamental transitions in the architecture of the continent that caused or conditioned the paleogeographic and facies changes are briefly reviewed.

The major events as interpreted from the stratigraphy, structure, and other features of the geology are the following:

1. Late Proterozoic diastrophism.
2. Upper Cambrian marine transgression and wide-spread late Cambrian-early Ordovician sedimentation, with less extensive deposits of Middle and later Ordovician and early Silurian time.
3. Main Caledonian orogenies of late Ordovician to Silurian, and a general withdrawal of the seas during much of the Silurian. The best developed Silurian seaways, as in North America, are apparently in the eastern part of the continent.
4. Marine advance in late Silurian and Lower Devonian. An extensive development of Lower Devonian sediments, which embrace the major part of the Devonian age sediments of South America. However, a Middle Devonian marine invasion spread through the Colombia-Venezuela and Amazon troughs and southward down the Cordilleran trough at least as far as 20°S Latitude.
5. Upper Devonian sediments are unknown in South America. Mississippian marine sediments occur in the West-Central Argentine embayment and at least locally in the Colombian seaway; and they may yet be found in the Cordilleran trough of Perú and Bolivia, where continental beds of Mississippian and probably also Pennsylvanian ages occur.
6. Mid-Pennsylvanian marine sediments are known locally in the Cordilleran trough, but the first major marine advance following the Devonian began in the late Pennsylvanian and persisted through the early Permian. It covered approximately the same areas that were occupied by Devonian seas. Glaciation occurred south of about 20°S. Lat., and its deposits are interfingered with both marine and continental sediments in the southern areas. Less extensive, mainly continental sedimentation of later, possibly mid-Permian age, locally carrying glacial deposits in the south, rest disconformably on early Permian.
7. Marine sediments of Upper Permian and Lower and Middle Triassic age are not recognized on the continent. Some plant- and coal-bearing beds in Perú are thought to be mid-Triassic.
8. The sea advanced from the west in the Upper Triassic into the basins occupied by Permian sedimentation. The marine sediments interfinger with and change to a continental facies toward the margins of the advance. These continental clastics overlap beyond those of the Permian in many places.
9. A new pattern of geosynclines, whose formation began along the belt of the present Cordillera in the Triassic, is occupied by Jurassic sediments whose main seas existed in the Lias, Bajocian, and Callovian ages. Barred basins developed in these geosynclines. These were sufficiently closed to deposit salt and anhydrite in the Oxfordian stage.

10. A re-advance of the sea in the late Jurassic, Tithonian, spread sediments of Tithonian and early Cretaceous Neocomian stages through somewhat more extended areas of the western geosynclines, opening southward through Tierra del Fuego, and also extending for the first time across the northern part of the continent.
11. In the Aptian-Albian-Lower Cenomanian (Comanche) ages of the Cretaceous the Cordilleran seaways enlarged in the northern and northwestern areas and receded toward the new southern Patagonian embayment. A marine embayment appeared for the first time in the Bahía area of the Brazilian coast.
12. A withdrawal of the seas in the Cenomanian was followed in late Cenomanian and Turonian time by a wide marine advance over the areas of Aptian to early Cenomanian sedimentation. Deposits of this sea are most prominently developed in the Turonian and lower Senonian stages. As a preliminary to the uplift of the Andes, the over-all slope of the continental platform, which had been largely westerly during the Paleozoic and lower Mesozoic, began to take a more level stand. As a consequence, extensive, largely fresh-water lakes spread over the interior of the continent during the Upper Cretaceous.
13. Two or more relatively minor to locally more severe movements affected the continent in the late Cretaceous. The first caused a retreat of the sea in the Upper Senonian. In many parts of South America, as in other parts of the world, a well-defined hiatus separates the Tertiary from the Cretaceous. However, the seas advanced into the deeper parts of the troughs and embayments to deposit sediments of late Senonian to Paleocene stages.
14. The first major Andean orogenic movement of the Tertiary occurred in post-Paleocene, early Eocene time. A marine advance followed which spread widely in the middle Eocene, and there were further lesser retreats and prominent readvances in the upper Eocene.
15. A second major Andean movement had its climax in early Oligocene. This was followed by sea advances of middle Oligocene to early Miocene time.
16. The Oligo-Miocene deposits spread headward and inland and continued upward through the middle Miocene into brackish and still more continental facies, while they remained marine in character in more restricted episeas of the continental margins.
17. Upper Miocene brought a further general retreat of seas and a drying-up of interior areas preliminary to a third major Andean orogenic-epirogenic movement in late Miocene.
18. The seas readvanced into certain local embayments and marginal areas in the Pliocene.
19. Continental deposition continued along the Andean front in the Pleistocene as the fourth major Andean movement raised the Cordilleras to approximately their present conformation. Glaciation developed in the higher mountains and was general over southern Patagonia.
20. Taphrogenic breakdown and general subsidence of continental border areas and belts, which began in the Mesozoic, became more pronounced in the late Tertiary and Quaternary.

1. INTRODUCTION

Our understanding of the geology of the earth or any part of it is constantly undergoing change. This condition of change and growth as new facts come to light is one that is common to all sciences. Every geologic map is, in effect, a progress map, imperfect and vulnerable. Paleogeographic maps of South America for 20 principal deposition overlaps or units of sedimentation from the Cambrian to the Pleistocene were prepared by the writer 7 years ago in the course of developing similar broad regional studies of the earth. The accompanying maps incorporate various subsequent revisions and no doubt will require many more. With few exceptions, concerned particularly with certain parts and areas of the lower Paleozoic, it is felt that future revisions will be more in the nature of a refinement of detail and of facies distribution than in respect to the existence and general outlines of the major seaways and embayments.

The compilations are based on 22 years of growing familiarity with the geology of South America, about 15 years of which were spent in field study of many parts of the continent ranging from the Caribbean on the north to Tierra del Fuego on the south. In addition to this first-hand source of information the writer is greatly indebted to his colleagues in the field and to many sources of published information. A selected bibliography of several hundred papers, books, and other publications is appended for those who care to enquire more deeply into the geology of the continent. No doubt other good papers exist that have escaped the writer's attention.

The writer is not a paleontologist. Hence, he is much indebted to the paleontologists, particularly to those who are also stratigraphers and who are able to rationalize their findings by fitting them into the broad regional picture of stratigraphic similarities and facies changes and the fourth dimension, geologic time. There is no area of the earth, large or small, and no problem in geology that cannot be better understood when it can be visualized against a broader background.

In covering a subject as vast as that here involved within the limits of space and time available, only the barest outline can be presented. The paleogeographic maps are selected to picture the principal units of sedimentary overlap or "layers of geology". These chapters are fitted into the geologic story of the continent after we take a brief look at the continental framework with the aid of Figure 1, which shows the present structural (in contrast to original sedimentary) basin areas of the two Americas.



2. CONTINENTAL FRAMEWORK

The geologic framework of the continent of South America bears many similarities to that of North America. Chief of these are the following:

1. The right-angle triangular shape.
2. The great central stable shield or continental nucleus — Canadian shield in North America and Brazilian shield in South America, each covering a vast area in the northeast-central part of the continent.
3. The long mobile belt, consisting of asymmetric geosynclinal troughs and borderlands, which fringed the forelands of the stable shield areas on the west throughout most of geologic history and which, through a series of orogenies, developed into the lengthy Cordilleras of to-day.
4. The development of mobile belts, now marked by the southwest-trending so-called Brazilides of eastern Brazil and the middle Argentine ranges, that are broadly similar in respect to position, age, and trend, although on a very much lesser scale of development, to the Appalachian-Ouachita-Llanoria belts in North America.
5. The remarkable similarity of the West Indian arc, connecting North and South America through southern Mexico, northern Central America, the Greater and Lesser Antilles, and the northern Trinidad and Venezuelan coast ranges, with the southern arc which connects Antarctica with South America through Tierra del Fuego, Burdwood, South Georgia, South Sandwich, South Orkneys, South Shetlands, and the Antarctides. (It is evident that the connection between the two continents through Central America is not that of the ordinary tectonic mobile belt of the crust. As just stated, the tectonic mobile belt connection clearly follows the arc of the Antilles into its Andean continuation in South America. The more direct connection through Central America is rather clearly that of a volcanic bridge across the easterly embaying Pacific-Caribbean plate. The basic lavas forming that bridge and the similar lavas comprising part of the foundation of the Antilles rose incidental to the collapse of the Pacific-Caribbean areas. This collapse and the extravasation of the basic volcanic lavas to form the bridge occurred since the Cretaceous, just as the thousands of Tertiary-Quaternary volcanic islands and island ridges throughout the Pacific region rose during the same period which, on balance, was one of subsidence of the ocean plate.)
6. The similar spread of seas over the forelands and interior shield areas at similar periods from the major troughs and seaways that lay in the main on the west and southwest. Seas entered also at certain periods on both continents from the northeast and/or northwest.
7. The similar changes in general pattern of the paleogeography (shown on the accompanying maps in the case of South America) from that of the Paleozoic to that following the Triassic. On both continents new Mesozoic-Tertiary geosynclines opened along the backs or hinterlands of the Paleozoic mobile belts, extending from beyond Japan through southern Alaska and through western North and South America.
8. The high plateau-like widening and westward bulge in the region of the middle Cordilleras on both continents.

9. The marine overlaps of Cretaceous-Tertiary age from the east and southeast on both continents. These overlaps developed with the uplift of the Cordilleras, which brought about a change in the overall tilt or surface slope of both continental blocks from the westerly one that was generally prevalent prior to the Cretaceous to an easterly or southeasterly slope subsequent thereto.

10. The subsidence, largely occurring during the period from late Cretaceous to the present, of the hinterland belts of the Cordilleras beneath the waters of the Pacific along the coasts of both continents.

Numerous other similarities exist, many of which will be mentioned. However, there are differences of interest. One is the fact that, with few exceptions, the extent and the depth of epeiric seas was somewhat less in South America than in North America. Likewise marine conditions in South America were less prevalent or continuous and there was a lesser volume of sediments left by the seas than in the northern continent. Another difference is the fact that, relative to North America, there is a very low representation of carbonate rocks in the basin sediments.

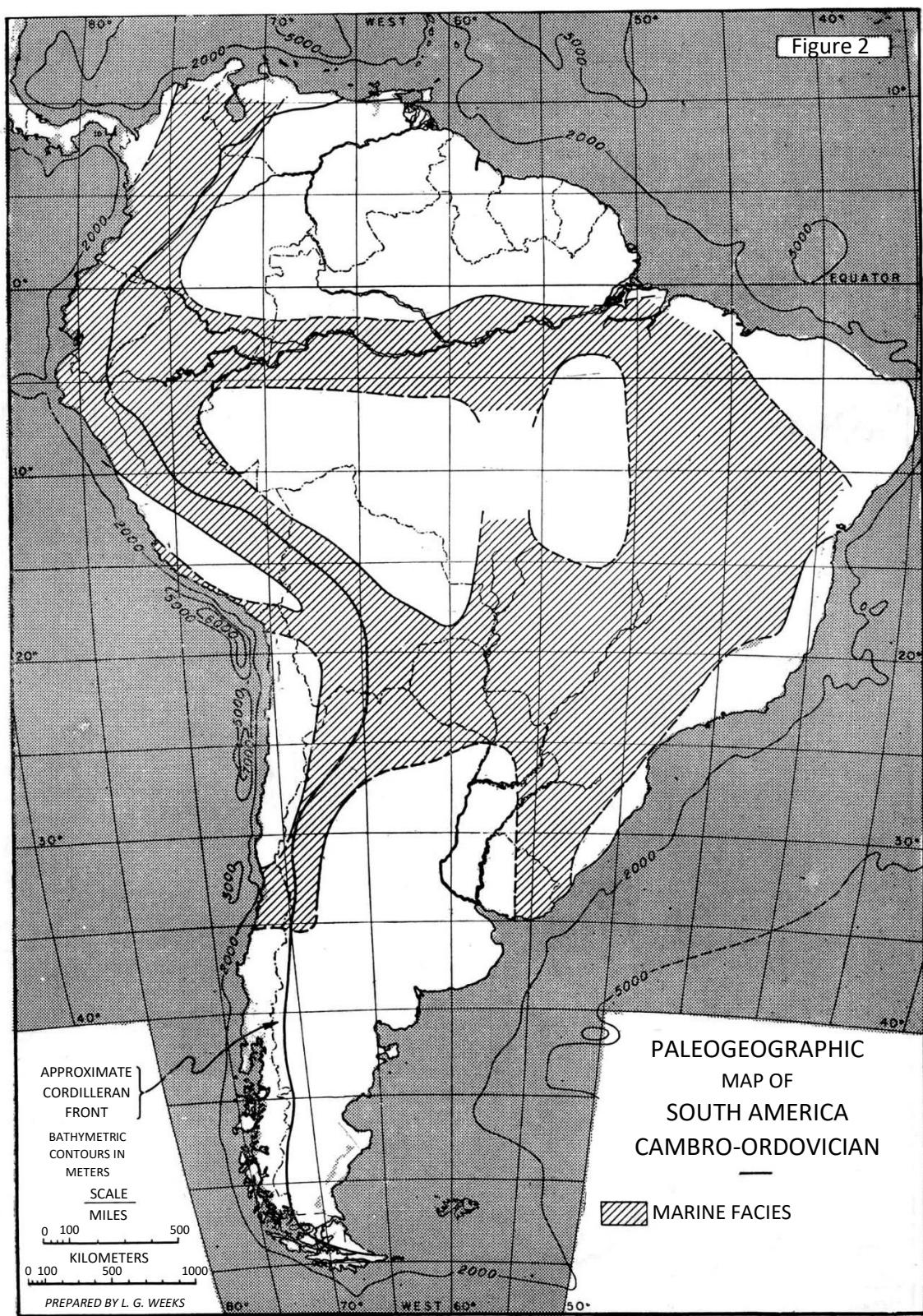
3. ALGONKIAN

Deposits of the Algonkian or late pre-Cambrian are difficult to differentiate in many cases. The picture is obscured by the fact that sediments of many ages up to even Triassic, Jurassic, and Cretaceous have been called pre-Cambrian at one time or another. Usually considered a part of the Algonkian are a series of highly metamorphosed sediments, including huge deposits of high-grade iron ore, deposited in an ancient north-northeast trending geosyncline in eastern Brazil. Other iron-ore deposits occur in Venezuela south of the Orinoco. These occurrences recall that of the Lake Superior iron ores of similar age. Southward along the same trend in Brazil and Uruguay, in northern Paraguay, in southwestern Matto Grosso, and in the Andean belt of northern Argentina, Perú, and Bolivia occur old metamorphics which have been considered as pre-Cambrian in age but part of which may very well be younger. Other local occurrences, particularly in southern Brazil and Uruguay, sometimes placed in the early Paleozoic, fit more logically in the late pre-Cambrian.

4. CAMBRO-ORDOVICIAN

As in North America the widest extent of the Cambrian seas was in the upper or late Cambrian. In fact, no lower Cambrian has been identified in South America. Latest Cambrian and/or lowermost Ordovician marine sediments are known in the Macarena and neighboring parts of south-central Colombia. Ordovician is present in the Merida Range of western Venezuela, at Puerto Berrio in the Magdalena valley of Colombia, and seems to be also represented at other places in northern Colombia. An Ordovician age is probably represented in the early Paleozoic sediments of southern Ecuador.

Middle and, particularly, Upper Cambrian marine sediments are known along the eastern Cordillera of Bolivia. This marine invasion transgressed southward into northern Argentina where it embayed in a less marine facies. Transgression continued in the Ordovician in the Cordilleran and pre-Cordilleran belt of Argentina, Bolivia, and Perú.



Various marine advances and retreats are indicated, but the principal Ordovician occurrences are lower and Middle Ordovician in age. Consisting largely of graptolite shales in the north, there is a change to a more sandy facies southward; while farther south, in the somewhat detached San-Juan-Mendoza area of west-central Argentina, where the beginning of a Paleozoic connection with the Pacific apparently existed, there occurs a well-known calcareous facies.

Cambrian faunas of the Cordilleran belt are said to show affinities particularly with the Pacific North American province, but rather early in the Ordovician faunas appear which indicate affinities with Atlantic-European waters. Possibly connections existed from the north through the Caribbean, from the east across a developing Amazon geosyncline, and across the middle of the continent through Brazil where early Paleozoic sediments of still insufficiently defined age occur.

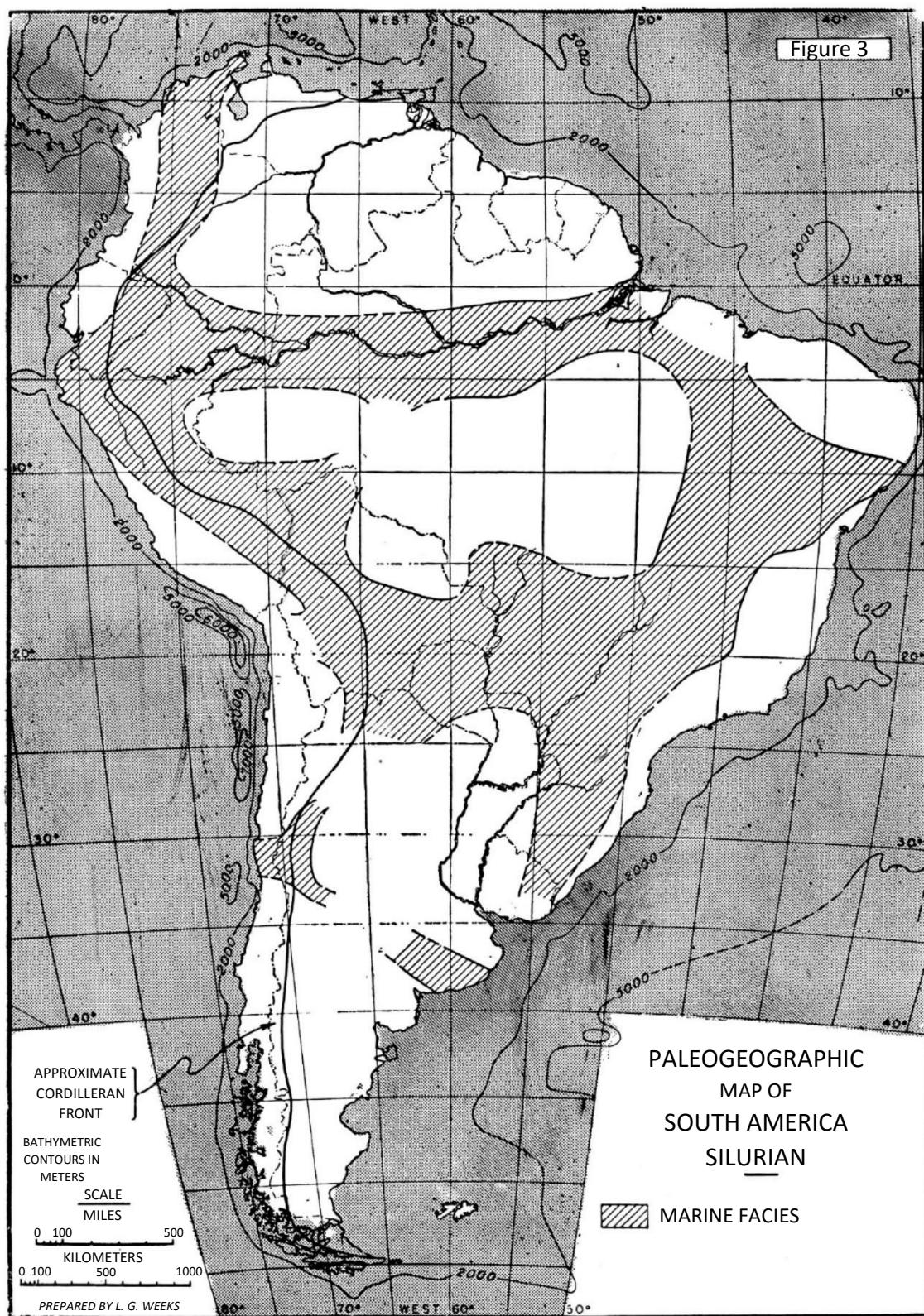
In 1942 Middle Ordovician graptolite shales were identified in the center of a domal uplift in northeast Perú near the Brazilian frontier, further suggesting that the Amazon Paleozoic geosyncline may have developed this early in the Paleozoic era. Indeed, the 1938 geologic map of the Ministry of Agriculture of Brazil shows the oldest sediments of the Amazon trough as questionably late Cambrian and they similarly map large areas of still insufficiently studied sediments extending across middle and eastern Brazil. Wherever early Paleozoic sediments are present in many parts of the world the Ordovician is commonly prominent. For this reason and also from the fact that the Ordovician seas were more widespread than the Silurian or post-Caledonian seas in other parts of South America, it is felt that the Ordovician will be found represented in many of the occurrences of pre-Devonian age in Brazil.

Some of the older sediments of Brazil and Uruguay, occasionally mapped as early Paleozoic, may be late pre-Cambrian. However, it is the writer's opinion that, in the absence of recognizable fossils, geologists in general are apt erroneously to ascribe too great an age to sediments that show a high degree of metamorphism. This error has been made in South America with respect to highly metamorphosed sediments, even as young as the Cretaceous, where these happen to occur in a belt that once was highly mobile.

No palaeontologic evidence of Paleozoic deposits has yet been found in the Patagonian Andes or at any other place in South America south of 38° S. Lat. But in the South Orkneys, about 700 miles southeast of Cape Horn, Middle Ordovician species of arthropod and of graptolite are reported to occur in sediments that have been altered to slates.

5. SILURIAN

It is principally the lower and the very latest Silurian that is found in South America. The early Silurian is present in the deeper parts of the Cordilleran seaway, particularly in Perú and Bolivia, as a continuation of the Ordovician graptolite-bearing sediments. It also occurs in the lower Amazon trough where it had possible connections westward, as shown, with the seas of the Cordilleran belt.



The extensive Bambuhy and older series of east-central Brazil have, by some, been considered Silurian in age, based on a very meager and insufficiently studied fauna. The writer feels certain on the basis of paleogeographic, stratigraphic, lithologic, and structural considerations, that these series are pre-Devonian. They may very well be Lower Silurian or Ordovician in age, or both. The paucity of fossils may be in part due to a semi-flysch character of much of the sediments, which were probably largely derived from the eastern mobile borderland and hinterland belt.

As is the case in North America, the Silurian of South America may have its best or widest development in the eastern part of the continent. Sediments possibly Silurian in age occur in Matto Grosso and westward. There are indications of a possible connection between the Amazon and Cordilleran troughs across the Beni area of northern Bolivia. The extension of the Silurian seaway shown on the map across southern Brazil and Uruguay is very questionable.

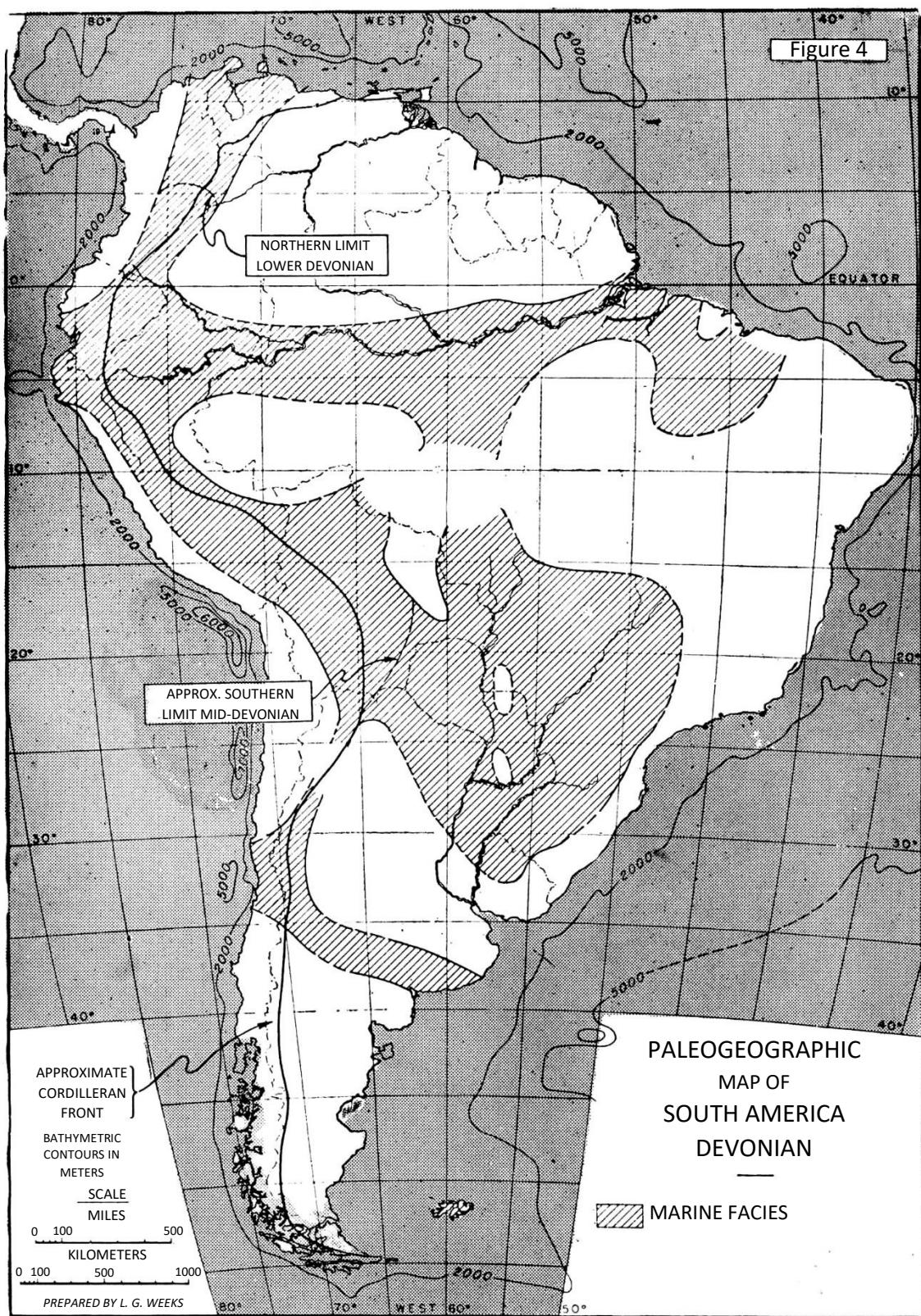
The sea appears to have withdrawn extensively or completely from the present area of South America during much of the Silurian, probably in response to the Caledonian (Taconic) movements that so widely affected the earth. In latest Silurian time a readvance of the sea occurred which continued through the Lower Devonian. These sediments occur in the Cordilleran trough of Perú, Bolivia, and Argentina and in the trough then developing across middle Argentina, and they probably are represented in the eastward transgressive advance of the Bolivian sea across Paraguay toward the Paraná basin of south Brazil and north Uruguay.

There are insufficiently confirmed indications that Silurian sediments are present in the Cordilleran belt of Colombia in the same trough belt occupied by the Cambro-Ordovician.

6. DEVONIAN

The sea advance which began in latest Silurian time spread eastward through the Chaco and Paraná basin areas and along the middle Argentine seaway and remained throughout the Lower Devonian. In the Cordilleran trough area of Bolivia and south Perú thousands of meters of flysch-type sediments accumulated. These were derived from lands newly raised by the Caledonian orogenies. In Bolivia and Perú sedimentation extended into the Middle Devonian. As a result of the Caledonian deformation in central Argentina the Cordilleran Devonian sea did not extend as far southward as did that of the Ordovician. In Brazil the Devonian consists of a prominent basal sand, overlain by shales which become somewhat more sandy at the top. Devonian sediments of South America are largely clastics, shales, and sands. The Lower Devonian sea spread also through the Amazon trough, and far toward the south it covered the Falkland Islands.

In addition to its occurrence in the central Cordilleran area, Middle Devonian is also present in the Amazon trough; and only Middle Devonian has so far been recognized in the Colombia-Venezuela trough, where, however, the occurrences are fairly widely distributed. Middle Devonian has not been recognized south of 20° S. Lat., unless a sandy facies which conformably overlies the lower Devonian shales in the Bolivian pre-Cordillera is of that age. Very recently field studies in the Maranhão basin, shown on the Devonian and on the Upper Carboniferous-Permian maps extending southward from the area of the mouth of the Amazon, revealed the presence of a Devonian marine fauna; hence, a Devonian embayment apparently extended into this area.



Lower Devonian faunas of all basins south of the Amazon basin have a characteristic, related austral or southern aspect. The Amazon basin Lower Devonian sediments contain a similar fauna but with an admixture of northern forms. The Middle Devonian of Colombia, of the Amazon basin and of Bolivia, while varying in ecologic conditions, all contain a related and essentially northern fauna, though in Bolivia there are thought to be present certain descendants of southern Lower Devonian types.

Upper Devonian time apparently found the seas withdrawn everywhere, though limited deposits of that age may yet be found in the areas of Middle or earlier Devonian sediments, especially in the troughs of greatest subsidence.

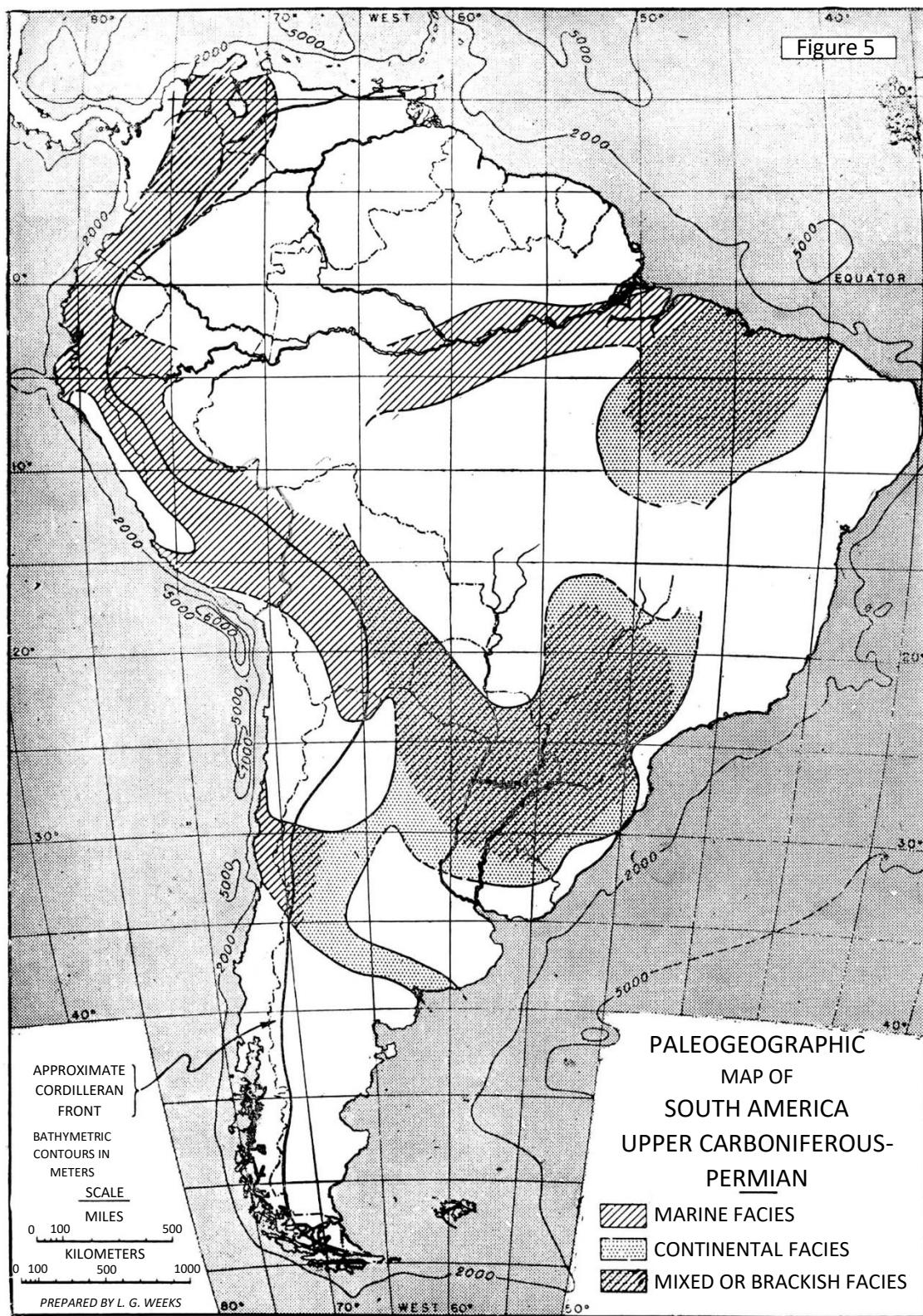
7. MISSISSIPPIAN

After the withdrawal of the Devonian seas from the area of the present continent South America remained above sea-level throughout the Mississippian period. Recently well-developed Mississippian marine sediments have been identified in San Juan and Mendoza in the embayment that extends eastward into west-central Argentina. As we have seen, this was a more or less continuous embayment. Pentremites and other Mississippian marine fossils have been reported in north-central Colombia.

In the Cordilleran belt of Perú and Bolivia sediments are present which are thought to be Mississippian in age. These appear to be largely continental in facies, but it appears not improbable that marine representatives will be found in the deepest parts of the belt of sedimentary troughs. An occurrence of questionable Lower Carboniferous sandstone has been reported near Monte Alegre in the Amazon trough.

8. UPPER CARBONIFEROUS-PERMIAN

Middle Pennsylvanian marine sediments and certain other marine and continental beds, less well defined in age, are known in the Cordilleran geosyncline of Perú, Bolivia, and northernmost Argentina. However, the first widespread advance following the retreat of the Devonian seas was of late Pennsylvanian-early Permian, or approximately Wolfcamp age. It has been common in the past to refer loosely to sediments of this age as "Upper Carboniferous". Deposits of this age form one of the most widespread overlaps of the continent. They cover approximately the same area as did the Devonian seas. In contrast with the Devonian, however, continuously marine sediments were deposited only in the deeper western parts of the Cordilleran troughs and in the Amazon geosyncline. Over the eastward extension of the Perú-Bolivia embayment, across the Chaco and Paraná basin areas the sediments have partly a continental-sea to brackish-water aspect, with only temporary intercalations of a true marine character. Southward, in middle Argentina, the formations are of an even more continental character, and the only marine sediments appear in the Cordilleran area of west-central Argentina and middle Chile.



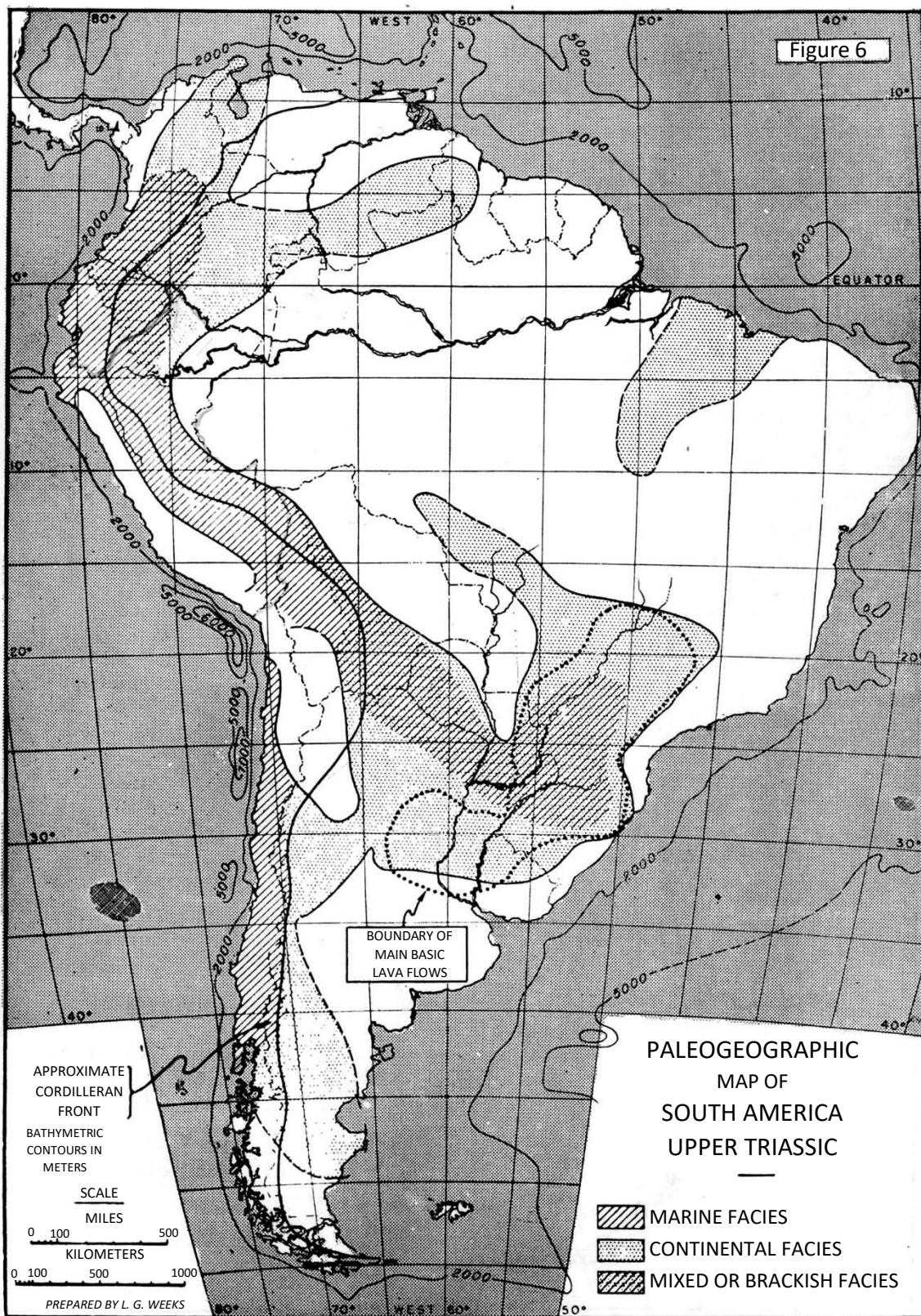
The Cordilleran trough marine facies of Perú and northwest Bolivia consists largely of shales and sands and *Fusulina*-bearing limestones. Southward and eastward the limestones rapidly disappear, and the amount of sand and silt increases. In Argentina and southern Bolivia, and eastward through the Paraná basin, glacial sediments appear at certain intervals in these beds. These locally faceted and striated but more commonly partly rounded constituents, as well as the accompanying finer clastics, were derived from neighboring highlands of eastern Brazil and of Argentina and Uruguay on the south, where glaciers developed in this, the so-called Gondwana ice age. In the marginal areas of Brazil and Uruguay and in the southern areas in Argentina these sediments are largely terrestrial or fresh-water in origin. They contain the characteristic *Gangamopteris* or Gondwana flora of the southern hemisphere, and associated coal beds. But in the deeper parts of the basins in southern Brazil, Uruguay, Paraguay, southern Bolivia, and northern Argentina the clastics were carried by streams and sometimes directly by glaciers or icebergs into waters that were in large part marine, and they contain a marine fauna.

The Amazon basin sediments, which make up a large part of the section in that basin, are of a similar, late Carboniferous to early Permian age, but the faunas are said to show a much closer affinity to those of North America, though still containing some of the forms of the Cordilleran trough. In northwest Perú and southern Ecuador occur marine shales and other sediments of this age in good development. Northward, in Colombia and western Venezuela, marine late Carboniferous-early Permian is locally very well developed. Continental beds also occur which contain the remains of a land flora. Far toward the south, Carboniferous continental glacial deposits overlap the Devonian in the Falkland Islands.

A controversy has long raged over the age of the Gondwana glacial deposits of South America. Some have preferred to place them in the late Carboniferous, others in the mid-Permian. In Bolivia and Argentina and in Paraguay, Uruguay, and Brazil there is a later series of Permian beds which we believe may be mid-Permian or approximately Leonard in age, which is also the age given for some post-Wolfcamp Permian marine beds locally present in Perú and in Colombia. These later sediments of Brazil and other southern areas were deposited in an interior sea of similar outline to that of the earliest Permian, but they are most predominantly of fresh-water character. In many places over the areas these deposits are seen to rest disconformably on the older Gondwana sediments without noticeable difference of dip. In Brazil and adjoining areas, a widespread zone of pyrobituminous shales, generally known as the Iraty shales, occurs in these deposits. In numerous outcrops in Argentina and southernmost Bolivia well faceted and striated clastics of a distinctly glacial origin occur approximately near the middle of this upper series and prove the existence of a second period of glaciation in those areas.

9. TRIASSIC

By the close of the Paleozoic the seas had completely withdrawn from the area of the continent and do not appear in evidence again until Upper Triassic (Keuper) time (Carnian and Norian stages). Some plant- and coal-bearing deposits in Perú have been considered mid-Triassic. In South America then, as in North America and many other parts of the world, the most widespread deposition occurred in the Upper Triassic.



Marine Upper Triassic of the Carnian and Norian stages occur in limited development in southern Ecuador, Perú, and Bolivia. No Triassic marine deposition is known in South America below these stages. The most characteristic marine Triassic formation is a limestone which is locally bituminous and commonly dolomitic and cherty, with silicified fossils and nodules. Eastward and southward (and to a much greater extent than in the late Carboniferous-early Permian) the Upper Triassic sediments become continental.

Marine intercalations of thin limestones, together with marls, silts, and shales occur in the upper Passa Dois of the Paraná basin of Brazil and Uruguay. There has been much controversy over the age of the Passa Dois. It is a perfectly conformable sequence. Yet, while the lower part has always been recognized as Permian some of the marine intercalations above were definitely considered to be Upper Triassic on the basis of the contained faunas. A recent restudy of these faunas in Brazil has resulted in the conclusion that they are Permian and not Upper Triassic.

Definitely established Upper Triassic sediments disconformably overlie the zone of marine intercalations. These consist of silts and sands, and the Triassic sequence closed with a widespread heavy-bedded sand deposition. Extensive basic flows are intercalated in the upper part of and follow this prominent sandstone. The Triassic of Brazil contains a flora and a reptilian fauna which indicates its Upper Triassic age.

In central and western Argentina Triassic continental sands and other clastics disconformably overlie and, in some areas, overlap beyond the Permian deposits. These continental clastics grade westward into marine Upper Triassic sediments of the Chilean trough. As shown by the maps, this trough was now becoming more prominent, and it continued so through the Jurassic and much of the Cretaceous. The Triassic fauna of South America appears to be mostly of a Pacific character and is related to the western Trias of North America.

No marine Triassic is known north of southern Ecuador. However, northward, in Colombia and western Venezuela, certain red and varicolored clastics, commonly referred to as the Girón series, probably are in part Upper Triassic in age. Characteristically, these sediments contain volcanic lavas and tuffs, as do so much of the late Triassic rocks of South America, and as do many of the westernmost deposits of North America.

In British Guiana, southern Venezuela, and adjoining parts of Brazil occur the prominent Roraima sandstone mesas with associated basic lavas. These sandstones are similar to the widespread late Triassic sandstones of central and southern Brazil; and the associated trap flows in the various areas are mineralogically similar. It is believed that the Roraima sandstones, as well as certain similar mesa-forming sandstones on the west in Colombia are, accordingly, Upper Triassic in age, though they may be somewhat younger.

The volume of the basic, but ordinarily olivine-free trap flows centering in south Brazil is probably the largest recorded on present lands in the earth's history. The main part of these flows spread over a maximum width of nearly 1000 kilometers and a length of fully 2000 kilometers. They cover much of southern Brazil, eastern and southern Paraguay, northern Uruguay, and northeastern Argentina in thicknesses ranging from 100 to more than 1000 meters. The flows are of similar age and mineralogic type as the Palisade flows of the Hudson River and certain other Triassic basalts of the western hemisphere.

Widespread in west-central and southern Argentina and adjacent Chile occur other Triassic igneous extrusives of a less basic character. These include porphyritic rocks, so-called keratophyres, melaphyres, and their equivalent tuffs. Not all of these are Triassic in age for this type of intrusive and extrusive activity continued in the Jurassic and even somewhat later along the Andean mobile belt.

The marine and fresh waters withdrew at the end of the Noric. Continental deposits in north Mendoza and adjacent areas of west-central Argentina, long considered to be Rhaetic in age, are now thought to be eastward equivalents of the Upper Triassic marine sediments that lie in the deeper basin on the west. The same may be true of most of Triassic continental deposits that occur widely in Argentina south of 27° S Lat.

10. LOWER AND MIDDLE JURASSIC

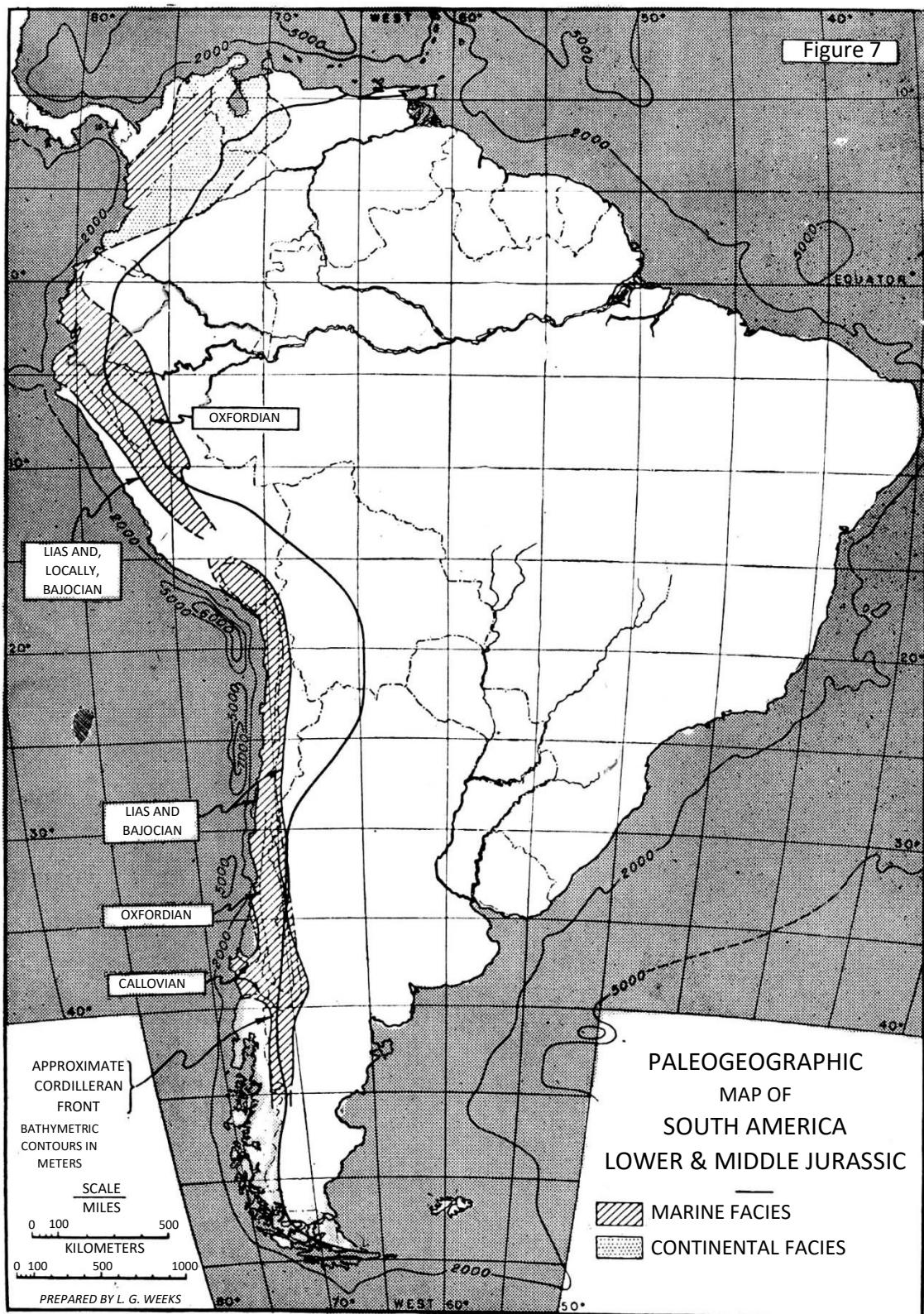
In South as in North America, and indeed in other parts of the world, the close of the Paleozoic and the opening of the Mesozoic brought a withdrawal of the extensive marine waters, together with an increase in continental deposition. At the same time there was initiated a new pattern of geosynclinal development which we see in the gradual change toward the Jurassic and later paleogeographies.

By Lower Jurassic (Lias) time the new Chilean geosyncline, which shows development on the Triassic map and even earlier, attained prominence. It extended for a distance of 30° of latitude, or from about 15° to 45° S Lat. The geosyncline was much wider than that shown on the map, which reflects the effect of the considerable post-depositional folding of the Andes. It is not certain, but possible that the Chilean geosyncline connected with that shown on the north in Perú.

Deposition was not continuous in the Chilean and Peruvian geosynclines during the Jurassic. Lias shales and limestones covered the greater part of the areas outlined. There was some withdrawal of the seas in the upper Lias, particularly in Perú. Marine Lias is known at El Banco in Colombia. This sea probably extended in along the main western trough of the embayment. The continental Girón beds in Colombia and equivalent beds in Venezuela, already referred to in connection with the Triassic, are thought to also include sediments of Jurassic age.

The sea readvanced in the Bajocian age of the lower Middle Jurassic (Dogger) over the greater part of the Lias areas of Perú and Chile and appears to have overlapped beyond the Lias in northern Chile and southern Perú. The seas then retreated again, with the result that the upper Dogger, Bathonian stage of the Middle Jurassic, is completely lacking, at least as a marine facies.

A re-advance in the Callovian age received Callovian stage limestones and shales over all of the northern and much of the middle and south-central parts of the Chilean geosyncline. Callovian sediments are not definitely recognized in Perú. If they were deposited there, as seems quite possible or likely, they may have been largely eroded during the diastrophisms that followed.



The moderate orogenic movements which caused the several marine recessions from late Triassic time onward were followed at the close of Callovian time in the Upper Jurassic by more severe orogenic movements. These led first to a closing off of extensive areas of the sea and the deposition of much anhydrite and/or salt and associated sediments in both the Chilean and Peruvian basins during the Oxfordian age. The extravasation of much volcanic material on the western side of the Chilean trough may have been partly responsible for the isolation of that basin. It is of interest, that salt and other precipitates of approximately Oxfordian age occur in Colombia, the Isthmus of Tehuantepec, the Gulf Coast of North America, and in the Mississippi Valley, in addition to the occurrences in Chile, Argentina, and Perú, and in the other parts of the world.

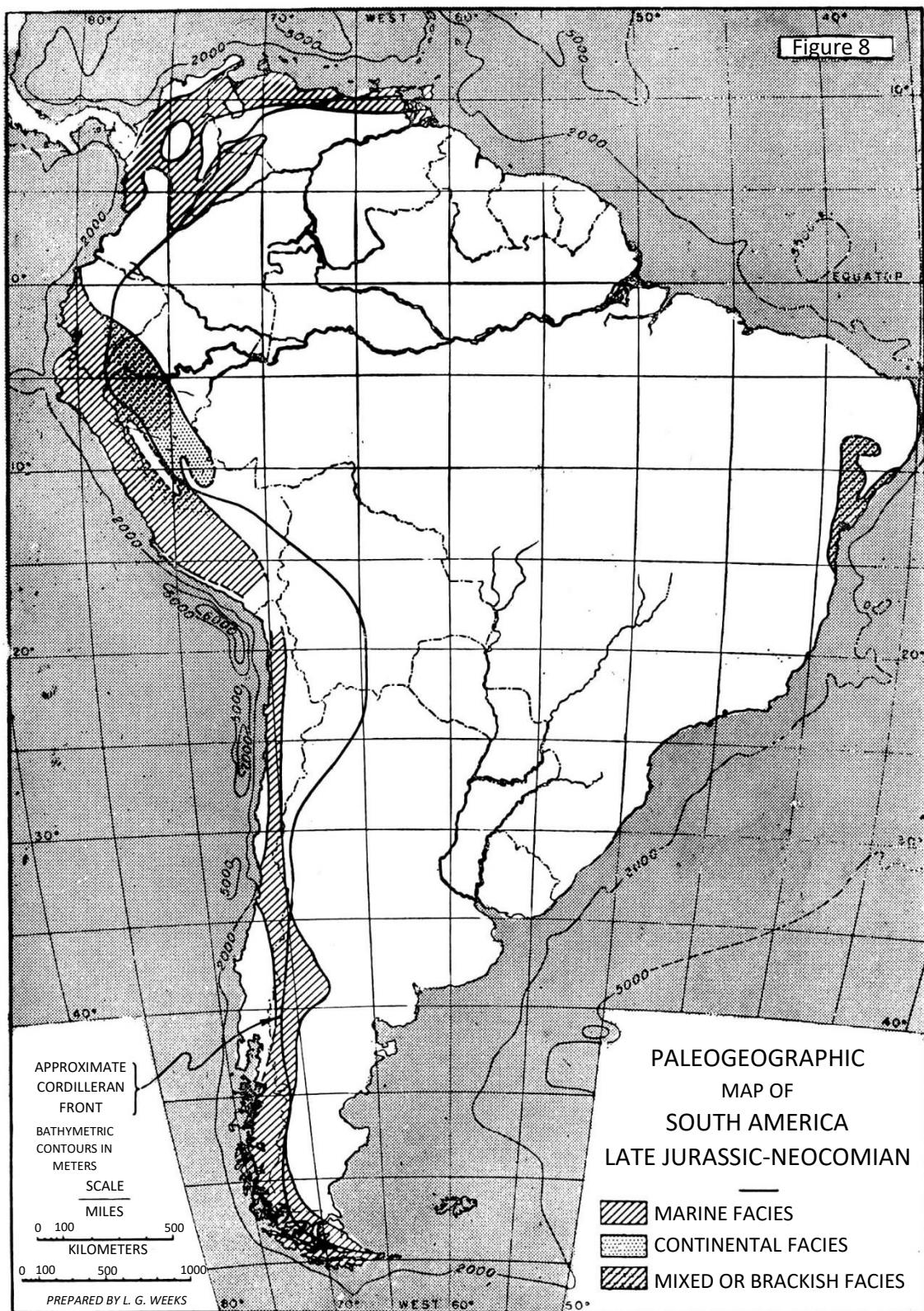
Corallian and Kimmeridgian stage sediments appear to be largely or completely absent in the geosynclines, though representatives of these stages may later be found. The most severe of the Jurassic orogenic movements occurred in late Jurassic, possibly Kimmeridgian time. This corresponds roughly with the so-called Nevadan revolution of North America. Various low arches, principally along the eastern Cordillera of Perú developed at this time.

As in western North America, the close of the Jurassic in the Portlandian or Tithonian age witnessed an extensive readvance of the seas, and a deposition that continued on through the early Cretaceous. The paleogeography of the Tithonian is shown along with that of the Neocomian on the next map.

11. TITHONIAN-NEOCOMIAN

The transgression which began in the Tithonian or closing stage of the Jurassic continued into the early Cretaceous. The paleogeography of the Tithonian and the paleogeography of the early Cretaceous (Neocomian) are essentially similar. Except for certain limited deposition breaks in Perú and possibly other places, they may be treated as a unit. This unit has its approximate counterpart in the Pacific belt of North America, in Mexico, in the subsurface of the lower Mississippi Valley, in the Wealden of England, France, and Spain, and in other regions.

In the Chilean trough, Tithonian brown and black shales and limestones are followed conformably by Neocomian shales, limestones, and sandstones. Most of this sequence is marine. During the period the trough rapidly extended southward from northern Patagonia and probably northward through Tierra del Fuego, permitting ingress of southern faunas and mixture with the Indo-Pacific faunas that prevailed at this period along the west coast of the Americas. Paleozoic and early Mesozoic marine sediments have not been definitely recognized in southern Patagonia or on Tierra del Fuego. Just as they do in the north Venezuelan Andes, the Cretaceous formations appear to transgress directly upon the crystalline basement, though local occurrences of older sediments may one day be identified in the south Patagonian Andean belt.



In Perú marine sediments of the period occur in good development on the coastal belt in the region of Lima. Here the Valanginian and Hauterivian stages of the Neocomian are particularly well represented. Eastward, toward the late Jurassic arch or arches, which, as already pointed out, developed along the belt of the present eastern Cordilleras, there is a change to a mixed marine and continental facies bearing some coals. In northern Perú, still little-known coals of this age occur, which may rank among the most important in volume and quality in South America. The earlier Tithonian, largely marine facies is best represented in the northern and northwestern part of the geosyncline, while it is mainly the Neocomian that extends into the upper part of the embayment south of 9° S Lat. East of the Eastern Cordilleran arch the Tithonian also thins out southward, and the Neocomian appears to consist largely of continental red or varicolored clastics, including much cross-bedded, possibly in part windblown, sandstones.

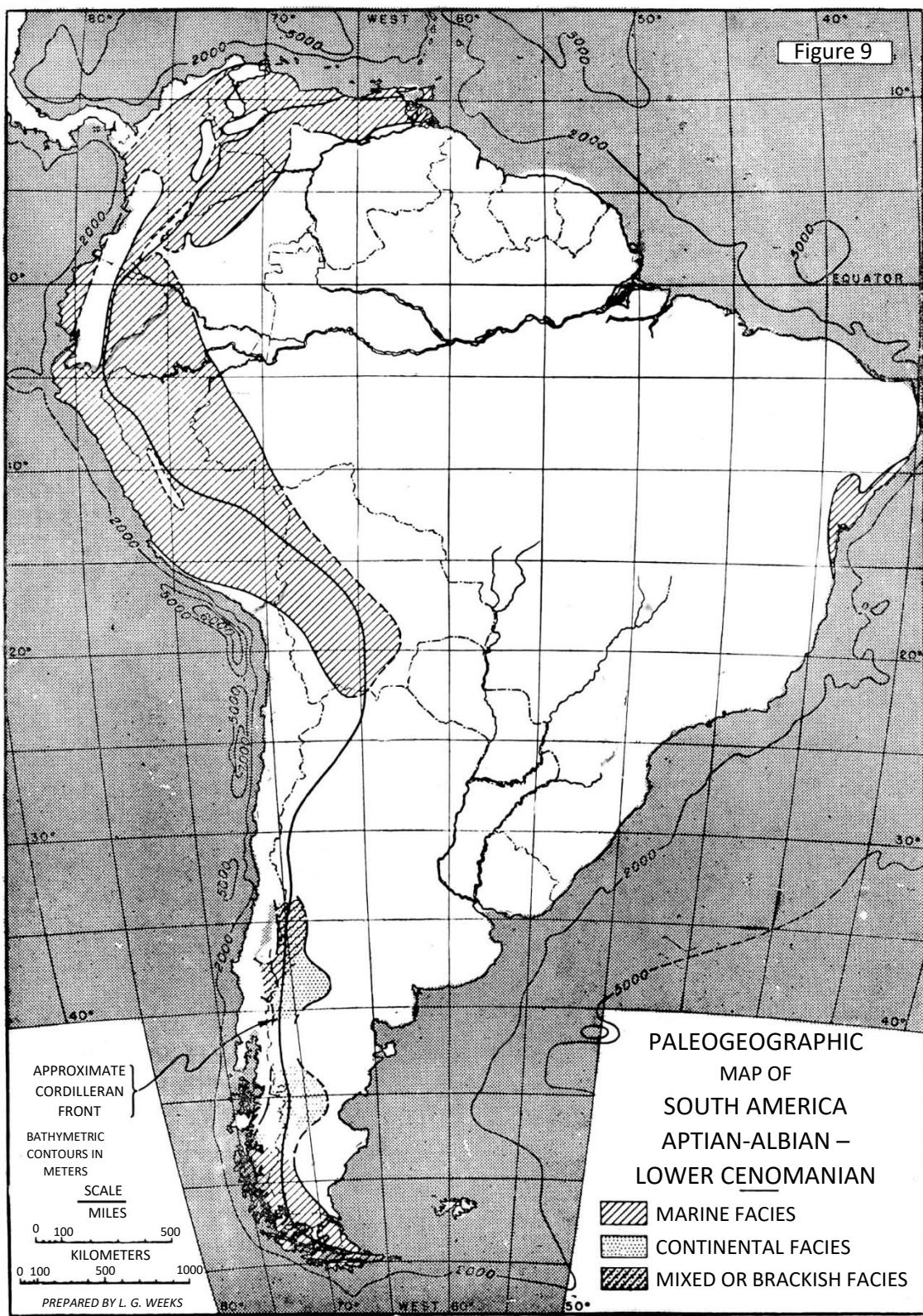
The late Jurassic-Neocomian sea of Colombia also spread eastward from the Pacific, and connected across northern Venezuela and Trinidad. From Trinidad to Perú the faunas of the seaways appear to have their main affiliation or connection with the Tethys faunas of Europe. While on regional and paleontological grounds it appears certain that the Cretaceous seaways extended through northern Colombia there is on the basis of present information some question whether the area covered by the seas across north Colombia was as extensive as is shown on the accompanying four Cretaceous maps.

In the newly developing Bahía embayment of the east coast of Brazil continental or brackish, possibly estuarine sediments of apparent pre-Albian age are included on the Neocomian paleogeographic map, though they may be Aptian in age.

12. APTIAN-ALBIAN-LOWER CENOMANIAN

The next map pictures the paleogeography of the continent in Aptian-Albian-Lower Cenomanian time, which is approximately equivalent to the Comanche of the Texas Gulf coast. At the southern end of the continent, the seas had largely withdrawn southward of 47° S° Lat., which area from this time onward became a prominent center of subsidence and deposition. Northward in this embayment, and in the Neuquen-Mendoza area farther northward, marine deposition gave way to a more continental facies in this period.

In the Peruvian embayment the Pacific seas spread inland and southward in the Barremian, Aptian, Albian, and Lower Cenomanian, depositing a marine shale, limestone, and sand facies. The Cenomanian, though spreading widely southward in Perú and Bolivia, is not generally of great thickness and is absent in many places, probably as a result of erosion during the mid-Cretaceous withdrawal of the sea, and subsequently. The base of this transgressive series is a prominent beach or near-shore type of sandstone, which appears to transgress time as the sea advanced, somewhat as does the Nubian sand facies of similar age in the eastern Mediterranean, or as does the basal Comanche sand of the United States.



In the Colombia-Venezuelan seaway a similar marine transgression and deposition mark the stages of this period. In the Bahía embayment marine sedimentation appears for the first time in the Albian. This heralds the beginning of a taphrogenic break-down of eastern lands, permitting the sea to reach the present coastal area of the continent for the first time since the mid-Paleozoic seaways crossed the present coastline.

13. LATE CENOMANIAN-TURONIAN-LOWER SENONIAN

The next paleogeographic map is designed to picture the Upper Cretaceous, from the late Cenomanian and Turonian through the lower Senonian. This period is approximately the equivalent of the Gulf series in the southern United States and of the Benton-Niobrara-Pierre of the Rocky Mountain front.

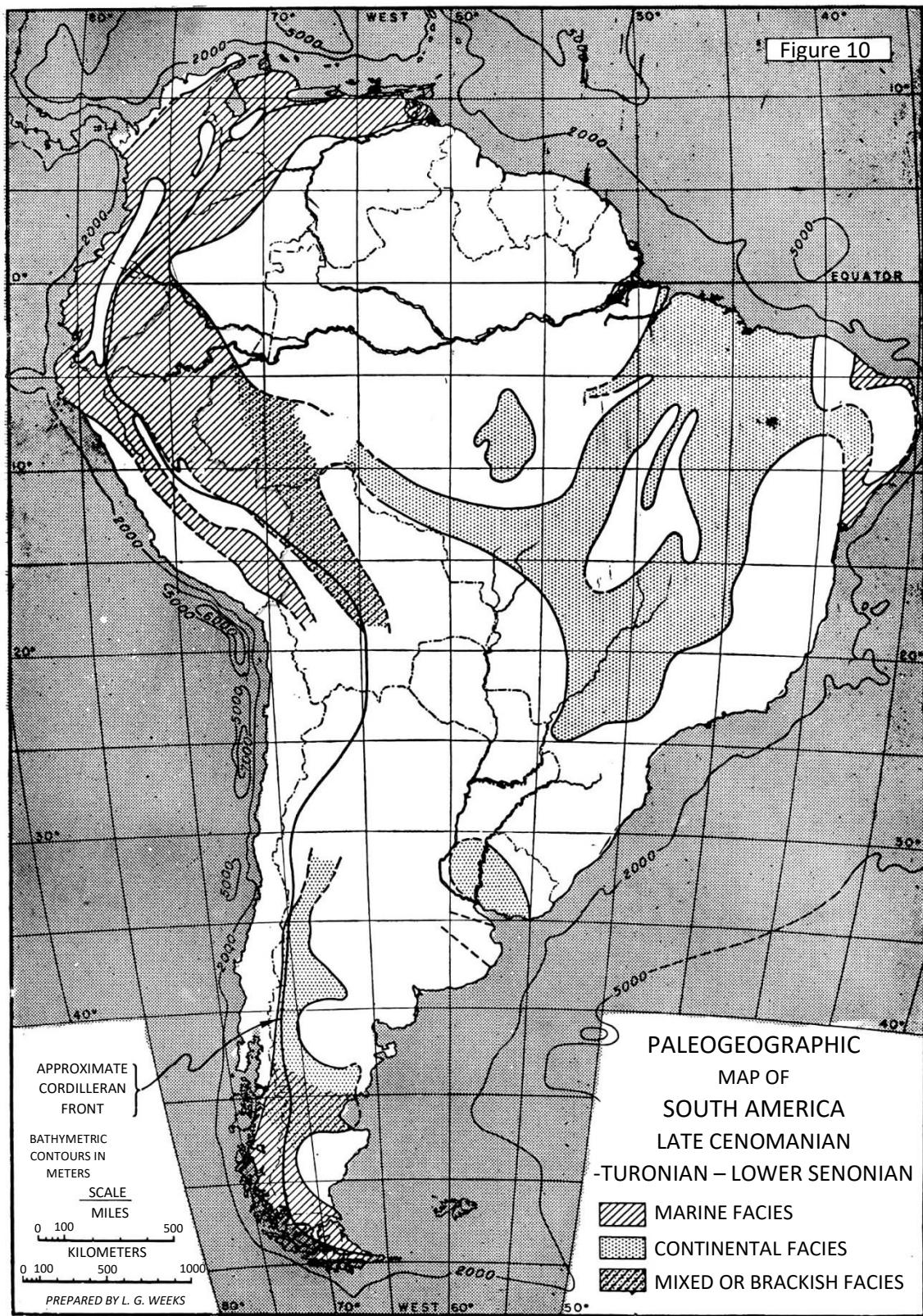
In the southern or Patagonian embayment there was marine deposition south of about 47° S Lat., northward from which there was gradation toward, and interfingering of marine with, a brackish and continental facies. The topmost sediments of the series in the continental facies areas contain the bones of large dinosaurs, as did the late Cretaceous swamps of Coahuila and Chihuahua, Mexico, and of Texas and Rocky Mountain basins.

In the Peruvian embayment the sea withdrew during the Cenomanian. Much of the Cenomanian and Turonian appears to be missing over the wide areas of the basin. In the northern part of the geosynclines, in north Perú and Ecuador, the presence of Upper Turonian marine sediments attests the re-invasion of the sea. The sea advanced rapidly through the Upper Turonian and Lower Senonian, spreading very widely in these stages when the bulk of the Upper Cretaceous sequence of marine shales, sandstones, and limestones were deposited.

In the Colombia-Venezuelan seaway there was the same mid-Cretaceous retreat and re-advance of the sea. The Upper Cretaceous transgression, as in Perú, spread more widely over the foreland than did any of the previous seas in this region. The backlands were beginning to rise, pushing the principal geosyncline forward. Embayments in the Bahía and Río Grande do Norte coastal areas of Brazil also received marine deposits during this period.

As mentioned previously in this review, higher land prevailed in the east and lower lands in the west during most of Paleozoic and Mesozoic history. In Upper Cretaceous time this situation began to reverse itself as the first incipient Andean uplift movements, forerunners of greater movements in the Tertiary, started to change the continental surface to a more level position.

In addition to a much wider overlap of the forelands by the seas, there developed, as a result of the levelling process, extensive interior fresh-water lakes, in which clastic sediments, but including also some locally occurring calcareous beds, were deposited. Principal of these Upper Cretaceous fresh-water deposits include the Cayuá and Bauru facies of Upper Cretaceous deposits and other similar sediments widespread over central Brazil. In Patagonia, also, the levelling process is reflected in the far eastward spread of the semi-continental deposits, which contain the dinosaur remains in their highest beds. Similar dinosaur-bearing beds occur in southwest Uruguay and adjacent Entre Ríos.



14. LATE SENONIAN-PALEOCENE

The final paleogeographic map of the Cretaceous represents the period of the late Senonian through the Danian-Paleocene. At the close of the Lower Senonian there was a rather general sea retreat in most areas. In places, such as close to the axes of deformation along mobile belts, the deformation was severe; but over wide areas the unconformity is not as noticeable or important as that of the main Laramide deformation immediately following the Paleocene. The records show that there was another marine advance and retreat in the late Senonian-to-Paleocene interval on the continent, as seen in Patagonia and in northwestern South America. With this general statement we briefly describe the new embayments and seaways.

In the Magallanes area of southern Argentina and Chile marine clastic deposition continued during much of the period. Farther northward in Patagonia, in the Comodora Rivadavia or San Jorge embayment and in the long northwest-trending Río Negro embayment, marine, brackish and continental beds of late Senonian-to-Paleocene age disconformably overlap Lower Senonian in embayments from the Atlantic. In addition to the disconformity at the base, at least one other occurs within the series itself in these embayments.

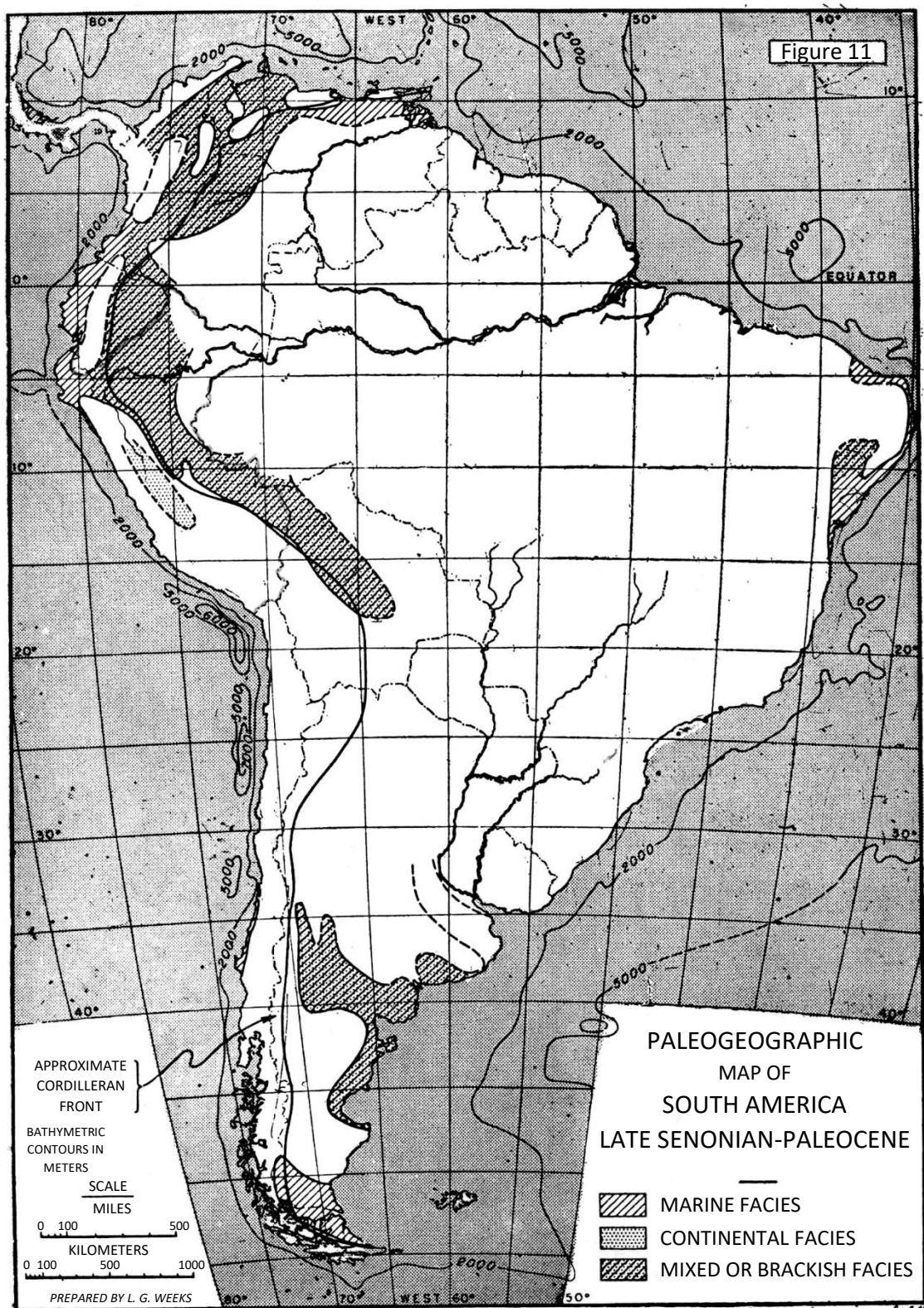
Under the city of Buenos Aires basement rocks have been found at about 300 meters depth. Between it and the Sierra Tandil about 250 kilometers south lies the axis of a Miocene embayment. Beneath this we have suggested the possibility of existence of a late Cretaceous embayment.

Farther north on the Atlantic coast marine deposition occurred in the Bahía and Río Grande do Norte embayments and in a very narrow belt along other parts of the coast.

In the Peruvian embayment the sea withdrew at the end of the prominent Senonian deposition. In the succeeding basin, which was somewhat more restricted in width by the now considerably emerged Andean belt on the southwest and by emergence of the foreland on the east, there was deposited a series of reddish to gray-colored sediments largely brackish to continental in facies but embracing certain marine intercalations. The sediments vary in facies and thickness along the trough of the embayment. From the limited fauna and from stratigraphic considerations, these sediments appear to range in age from late Senonian to earliest Tertiary or Paleocene.

The remnants of a trough within the Andean belt of Perú contain thick continental beds (such as the Rimac series) which have been considered to be late Cretaceous in age, but which are more likely wholly or largely Tertiary.

Along the Pacific coast of Perú and Ecuador occur latest Cretaceous-Paleocene sediments of entirely marine facies. South of Valparaíso on the western coast of Chile there is a narrow coastal overlap of marine sediments reported to be late Senonian in age.



In the Colombia-Venezuela geosynclinal belt the late Cretaceous-early Tertiary time interval varies laterally in the extent to which it is represented by sediments. In places beds as young as middle to upper Eocene or younger rest on strata as old as Lower Senonian or older. In other, deeper basin areas this interval is partly to largely filled in with corresponding shales and sands bearing late Cretaceous to Paleocene marine faunas. An overlap of this period occurs along the western part of the north Panama coast.

Throughout the western hemisphere, and indeed in most parts of the world where Paleocene sediments occur, these sediments in their facies and general affiliations appear more akin to the Cretaceous than to the Tertiary proper, whose first sediments commonly follow in middle Eocene time, or even later.

15. EOCENE

While early orogenic movements initiating the uplift of the Andean belt occurred within the Cretaceous, the first major Andean movement of the Tertiary period followed the Danian-Paleocene stage and had its climax in the early Eocene. This corresponds with the main so-called Laramide movement in the North American part of the Cordillera, and to diastrophisms at the same time in other parts of the world.

Except in the deeper basin parts, lower Eocene sediments are not prominently developed in most areas. The sea advanced again following the first Andean movement and, though interrupted by relatively less important disturbances and deposition hiatuses, the middle and upper Eocene witnessed the widest advances of the sea and received the bulk of the sediments of the Eocene epoch within the present limits of the continent.

In the southern Patagonian or Magallanes embayment the Eocene appears to be represented by a clastic, largely marine facies. In the Comodora Rivadavia or San Jorge embayment a continental facies bearing an Eocene land fauna is represented. Sediments of the same age are reported in the Río Negro embayment and, though unconfirmed, they may also be present in the Buenos Aires embayment. Eocene sediments have been reported to occur in the largely continental facies of the Tertiary in the Bahía embayment and along the coastline of Alagoas and Sergipe on the north.

Eocene sediments occur in a thick clastic marine sequence in the coastal embayments of northwest Perú and in southwestern and western Ecuador. A number of disconformable hiatuses are present in these largely middle and upper Eocene deposits. While Eocene sediments have not been definitely identified east of the Andes it seems likely that they may occur there in a brackish to continental facies which had westward connections with the coastal areas.

Eocene, mainly middle and upper, is well represented by a thick series of marine clastic sediments through the basins of northern Venezuela and Colombia, with southward embayments of a less marine character. Sediments of similar age occur in Panama.



16. OLIGOCENE-EARLY MIocene

What may be termed the second main Andean movement had its climax in early Oligocene time. This disturbance is commonly marked by a withdrawal of the sea starting in late Eocene or early Oligocene and, in many places in northwestern South America, by moderate to severe deformation followed by an overlap of middle to upper Oligocene.

A well-defined marine transgression of middle-to-late Oligocene time occurred in the Patagonian embayments. Transgression began somewhat earlier toward the south and sedimentation reached somewhat greater thicknesses successively from north to south in the several embayments shown on the map. There has been some difference of opinion among paleontologists concerning the position of the boundary between the Oligocene and the Miocene in many parts of the world. In general, in South America Oligocene marine sedimentation continued into or through the lower Miocene, though there is some marginal or headward and also upward gradation into brackish and continental deposits.

Little seems to be known of the extent to which transgression and deposition of the upper Oligocene-lower Miocene period occurred in the Buenos Aires or La Plata embayment. There are indications that the maximum transgression in this embayment was somewhat later in the Miocene (see middle Miocene map). Likewise, in the Bahía embayment the age of the largely non-marine Tertiary sediments is still uncertain.

On the west coast of Chile sediments of this period appear to be represented in the small Arauco embayment. Marine overlaps of this period are well represented in the coastal embayments of western and northwestern Perú and of Ecuador.

In Venezuela and Colombia a prominent Oligocene-lower Miocene sea transgressed from the northeast and north more or less widely across Eocene and older rocks. East of the Andes this transgression extended as a semi-marine to brackish and continental facies into Ecuador and Perú, though the existence of archipelagic conditions at the time along the Andean belt would have permitted connections with the Pacific. Eastward, along the middle and lower Amazon trough, all of the Tertiary deposition appears to be continental in character.



17. MIDDLE MIOCENE

The transgression of seas which followed the second major Tertiary orogenic-epirogenic movement of early Oligocene age and which spread through the upper Oligocene and early Miocene, continued, with minor interruptions marked by lesser hiatuses, through the middle Miocene. Clastic deposition, derived mainly from the rising Andean belt, was widespread. Sedimentation was so relatively rapid in the middle Miocene basins and embayments that there developed a general retreat of marine and brackish conditions from the positions attained by the sea advances during the Oligocene and early Miocene.

The relative extent of this largely continental deposition and the changing conditions may be visualized by comparing the middle Miocene map with that for the upper Oligocene-early Miocene. Some of the interior continental deposits shown on the middle Miocene map may be in part equivalent in age to earlier Miocene.

The extent of the La Plata marine embayment northward and northwestward is as yet incompletely determined. In the Oran basin of Jujuy and central Salta in northern Argentina the local very high salinity of formation waters indicates a temporary isolation of this area.

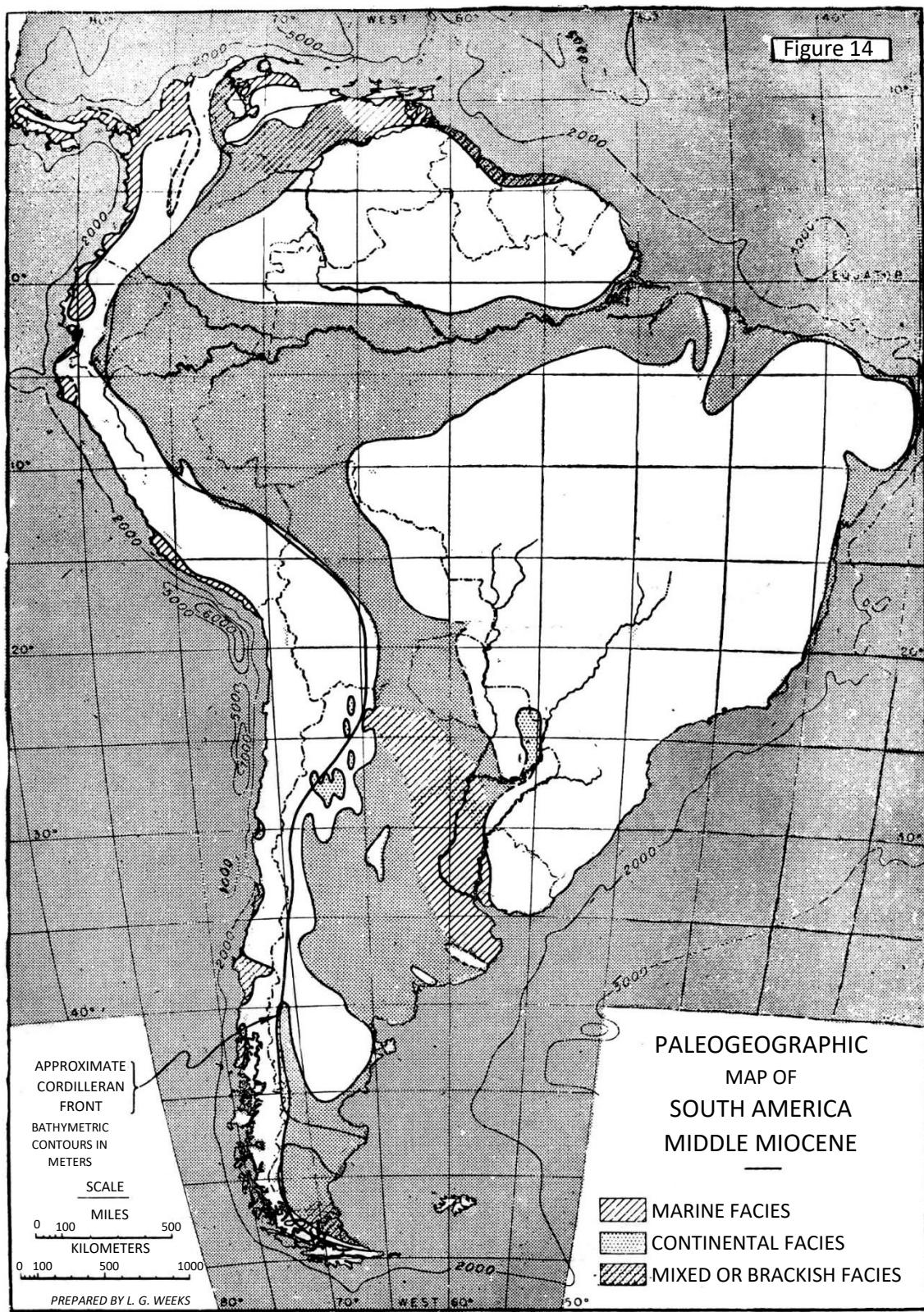
Continental deposition continued throughout the pre-Andean and Amazon troughs, while in the embayments of the Pacific coast, conditions remained prevailingly marine. With the increasing rates of deposition there was also in Venezuela and Colombia a rather general recession of marine facies toward the deeper outer areas of the embayments.

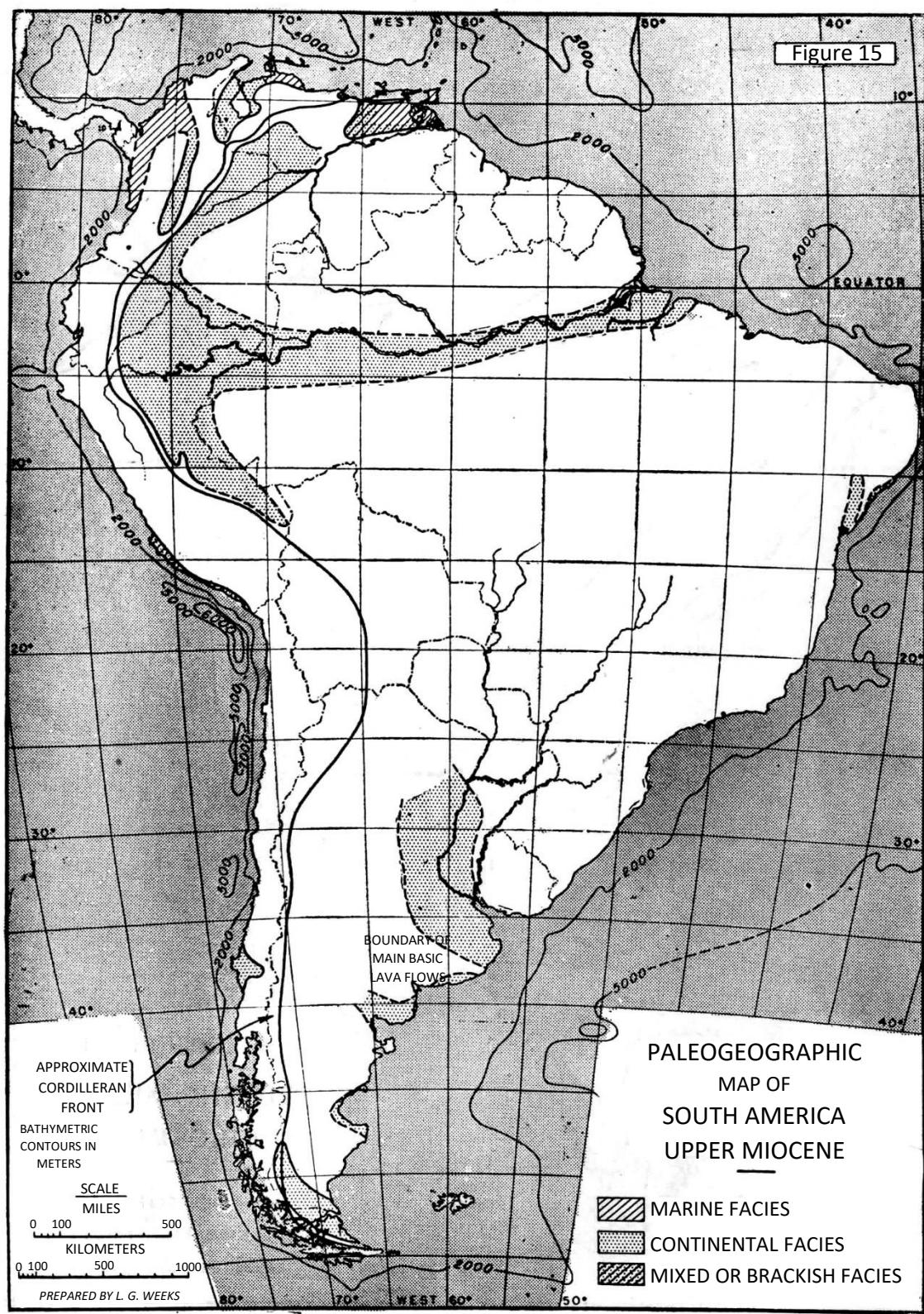
18. UPPER MIOCENE

The increased rate of clastic deposition in the middle Miocene brought about a filling of the basins, preliminary to the third major Andean orogenic and epirogenic uplift which had its climax in the upper or late Miocene. The upper Miocene map shows the approximate conditions of upper Miocene time immediately preceding this main movement, which in general corresponds with the so-called Attic diastrophism of Europe.

19. PLIOCENE

Marine deposition of Pliocene times is rather well developed in many basins of Europe and the Mediterranean regions and in other areas of the eastern hemisphere, as well as in the basins along the western coast of North America. In south America, Pliocene marine deposition is restricted to the outer parts of certain embayments, though continental deposition continued in the old geosynclines of the interior throughout Pliocene and much of Pleistocene time. The largely continental sedimentation was brought to a close in all except limited localities by the fourth major Andean orogenic and epirogenic diastrophism which had its climax in early Pleistocene time when the seas of the earth withdrew outside the present continental shelves along many or most of the coastlines.





A well-defined Pliocene marine embayment was present in southern Patagonia, and limited marine deposition of this period occurred in the La Plata embayment. On the northern and western coasts of the continent marine deposition was of very limited extent during the Pliocene.

Glaciers developed in Pleistocene time in the southern section of the Cordilleras, and the effects of this period of glaciation are general over the southern half of Patagonia.

Beginning in the Mesozoic and continuing throughout the Tertiary, but most particularly in late Tertiary and Quaternary time, there is much evidence of taphrogenic breakdown and marked subsidence of the Pacific and Atlantic border belts, as well as in the Caribbean-Gulf of Mexico areas. Along the whole length of the Andes and in the Mexican, Central American, and Antillean regions, as well as in western North America, considerable volcanic activity and extravasation of lavas accompanied the mountain uplift and the down-faulting and subsidence of border areas beneath the seas.

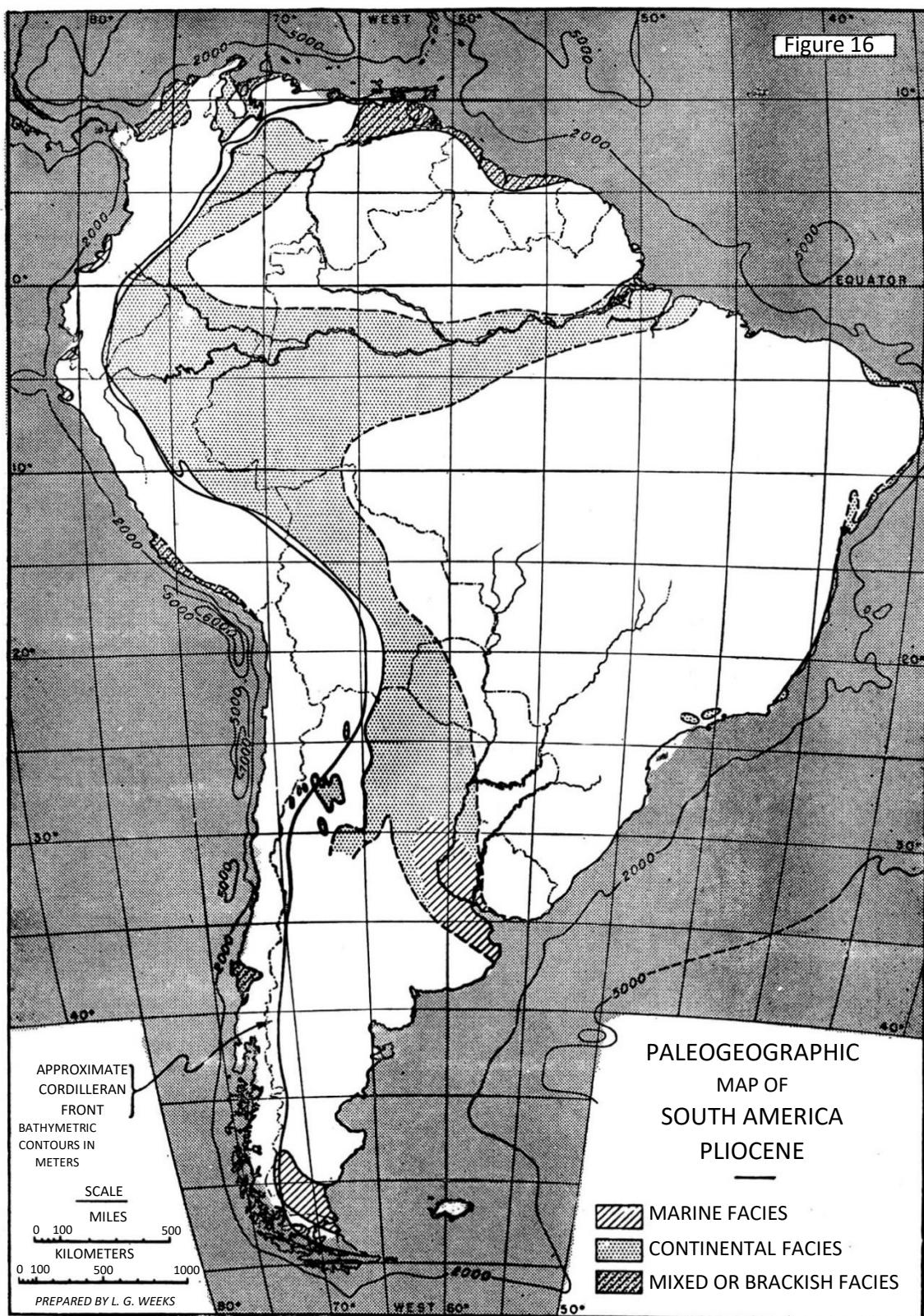


FIGURE 17



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PALEOGEOGRAPHIC DEVELOPMENT OF SOUTH AMERICA¹

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ABSTRACT

The post-Proterozoic geologic history of South America was controlled by the distribution and interplay of certain major geotectonic units, classed in five groups, which form the structural framework of the continent: *cratons* (Guiana, Central Brazilian, and Coastal Brazilian shields), *intercratonic basins* (Amazonas, Parnaíba, São Francisco, and Paraná), *pericratonic basins* (Llanos-Iquitos-Acre-Beni-Chaco-Pampas plains), *nesocratons* (Pampean Ranges, Patagonia, and Deseado massifs), and *geosynclines* (Andean belts).

Since Early Cambrian time the cratonic and nesocratonic areas have maintained stable to substable positive tendencies, the intercratonic and pericratonic areas have shown vertical substability to submobility with intermittent but decreasing subnegative tendencies, and the western geosynclinal belts have been highly mobile, deformable elements with recurrent negative tendencies, which have witnessed the main sedimentary-tecto-magmatic activity of the continent.

The paleogeographic development of South America since Cambrian time is summarized in 46 maps arranged in 33 figures, covering different geological intervals. Marine, continental, and mixed or brackish-water facies are differentiated, and the main areas of volcanic and glacial accumulation are plotted. The explanatory text — essentially a list of the main areas of exposure of the different stratigraphic units — makes brief references to the main diastrophic, volcanic, and glacial episodes.

1. INTRODUCTION

In 1947, L. G. Weeks published a set of 16 paleogeographic maps of South America covering different geological intervals from the Cambrian to the Pliocene. The maps, evidently the result of a careful analysis of the data available at that time, offer as good a summary of the sedimentary history of the continent as it was possible to make 15 years ago — even if we were to dissent from some of the interpretations. The geologic knowledge of South America, however, has made such rapid strides during the last decade that some of Weeks' maps and underlying assumptions need considerable revision.

In the following pages an attempt is made to summarize what is known at present about the paleogeographic development of South America. The considerable increase in our knowledge is reflected in the fact that 46 maps, arranged in 33 figures, are now offered instead of 16. As Weeks rightly prophesied, the increased number of maps is due mainly to our increased knowledge of the Paleozoic geology of the continent. The accompanying text is little more than an incomplete catalogue of the main areas where different rock units have been recognized, besprinkled with some quasi-telegraphic and far too positive assertions which form the kernel of the inevitable generalizations underlying the apparent objectivity of the maps. The appended bibliography lists only the papers, mentioned in the text, judged essential and sufficient for this purpose. Clearly no complete bibliography of South American geology can be expected here, as such a list would cover a whole volume of this journal.

As L. J. Willis pointed out in the preface to his *Paleogeographic Atlas of the British Isles* (1951), "when one sets to make a paleogeographic map, one is faced with having to come to decisions over many difficult problems which a less objective approach allows one to shelve. The great risk, as I see it, is that the reader may be misled into thinking that each or any of the maps (and for that matter, the brief and far too dogmatic text that accompanies it) gives an accurate picture of the geography of the period which it is designed to illustrate. Rather must it be emphasized that each map is at best an imperfect attempt to synthesize interpretations on stratigraphical data".

It can not be sufficiently emphasized that paleogeographic maps are, at best, subjective syntheses born out of a personal appraisal and interpretation of numerous observational facts. The accuracy and detail of the maps are directly related to the quantity and quality of the data, but no matter how abundant or how high their excellency and reliability might be, the cartographic representation is a subjective "possibility" deeply tinged by the author's ideas and personal experience. With the same set of observational facts two different authors may arrive at two different paleogeographic pictures, the divergence increasing in inverse relation to the number and accuracy of the data. When a wealth of observational facts is at hand and the map covers a small area, the two interpretations may be closely similar, but when the data are scarce and unevenly distributed over a region of continental proportions, then the subjective leavening becomes the dominant factor and the two pictures may be widely at variance.

Again, to quote Willis "the student of geology must forgive the many errors that the maps contain — errors of omission, of misinterpretation and of judgement", a plea which, if deemed necessary for paleogeographic maps covering such a well known and comparatively small area as the British Isles, becomes a thousand-fold more necessary for maps attempting to illustrate past conditions over such a large and unevenly known region as the whole South American continent.

2. STRUCTURAL FRAMEWORK OF CONTINENT

The study of the geological constitution of South America and of its structural development brings out the fact that, since Early Cambrian days, the sedimentary and tectonic history of the continent has been controlled by the distribution and interplay of different major geotectonic units forming a well defined structural framework which, born at the close of the Proterozoic after a lengthy gestation period during the hazy Precambrian evolution of the continent, has remained essentially unaltered to the present time.

On the basis of their degree of vertical stability, of the positive or negative tendencies which they displayed during their geologic history, and of the degree of tangential deformation which they underwent during periods of uplift or compression, five groups of major geotectonic units can be distinguished and briefly characterized (Fig. 1).

i. Cratons. Stable, positive, undefinable units: (a) Guiana shield, (b) Central Brazilian shield, (c) Coastal Brazilian shield.

ii. Intercratonic basins. Substable, subnegative, undefinable units interposed between the cratonic areas and superimposed on former Precambrian geosynclines: (a) Amazonas basin, (b) Parnaíba basin, (c) São Francisco basin, (d) Paraná basin.

iii. Nesocratons ("islands shields"). Substable, subpositive, undefinable units separated from the cratons by negative belts: (a) Pampean Ranges massif of Argentina, (b) Patagonian massif, (c) Deseado massif.

iv. Pericratonic basins. Submobile, subnegative, subdeformable units located along the western border of the cratonic and intercratonic areas: Llanos-Iquitos-Acre-Beni-Chaco-Pampas plains.

v. Geosyncline. Mobile, negative, deformable units located along the western border of the pericratonic basins or nesocratonic areas. They include all the Paleozoic, Mesozoic, and Tertiary active belts of South America.

Some comments on the different geotectonic units and a brief history of their evolution may clarify the concepts.

2.1 Cratons

As pointed out by Caster (1942) it now seems reasonably certain that the "core" of South America consists of three distinct cratonic areas formed of Early Precambrian rocks. These are (a) the Guiana shield, located between the Orinoco, the Atlantic Ocean, and the Amazonas valley, (b) the Central Brazilian shield, lying between the Amazonas valley, the Beni-Chiquitos-Chaco plains, and the Paraná-São Francisco-Parnaíba basins, and (c) the Coastal Brazilian shield, interposed between these basins and the Atlantic Ocean.

Though the three ancient cratonic areas are regarded as formed mainly of Early Precambrian ("Archaeozoic") rocks, it is now evident that the northern belt of the Guiana shield, as well as those areas of the Brazilian shields facing the intercratonic and pericratonic basins, are mostly formed of younger Precambrian metamorphics welded to the ancient cores.

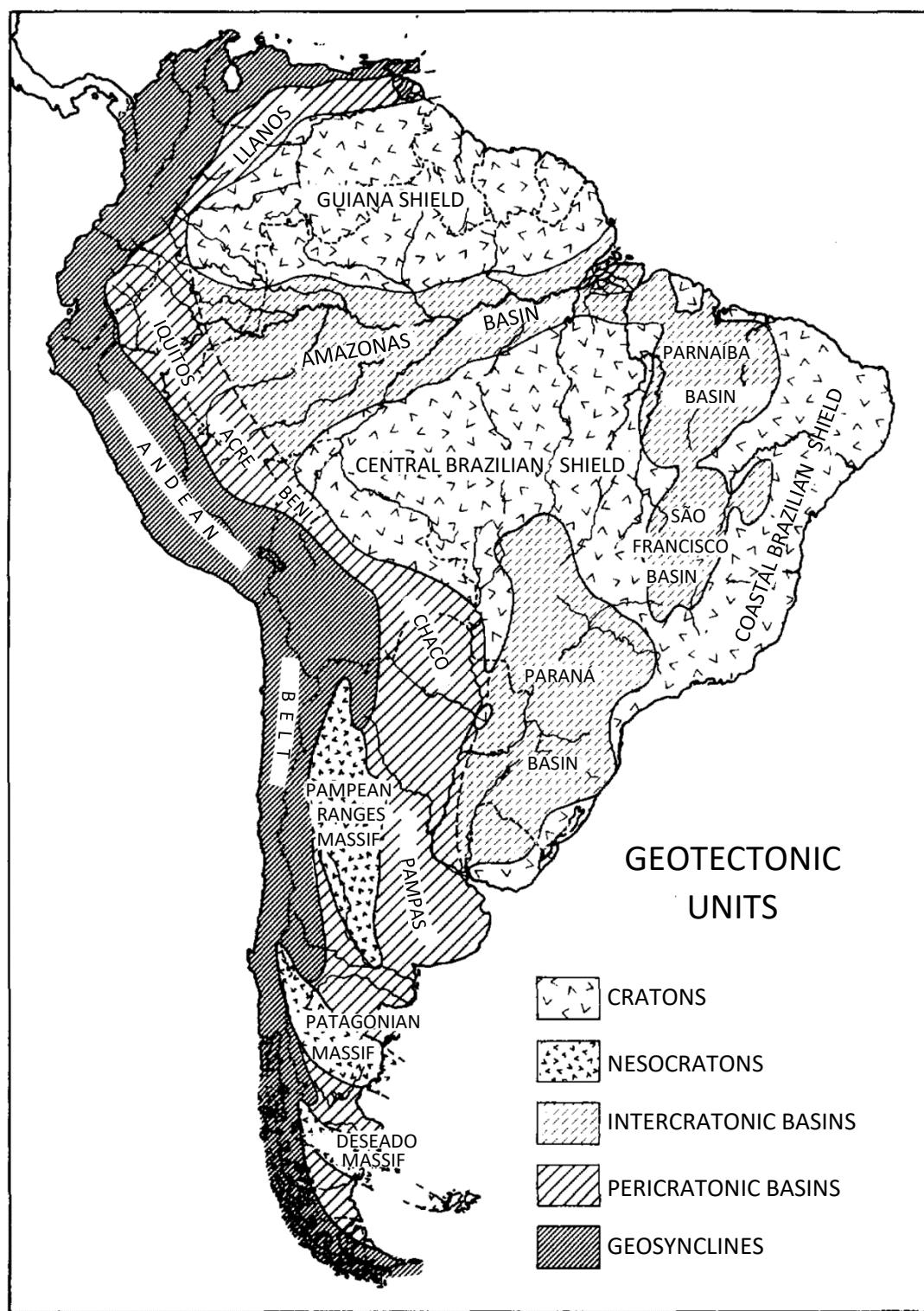


Fig. 1. – Geotectonic elements of South America since Early Paleozoic time.

The cratonic regions seem to have remained emergent since Middle Precambrian time and only rarely their marked positive character gave way to a transient sub-negative tendency resulting in the accumulation of continental beds (Triassic over part of the Guiana shield, Cretaceous over parts of the Central Brazilian shield). Since Early Cretaceous time, however, a narrow strip of the Coastal Brazilian shield has developed sub-negative tendencies as the result of protracted downfaulting.

2.2 Intercratonic basins

2.2.1 Region interposed between Central and Coastal Brazilian shields. During Middle Precambrian time this region, which is now occupied to a large extent by the Parnaíba, São Francisco, and Paraná basins, was the site of a large eugeosyncline of general northeast to southwest direction. Middle Precambrian rocks flank both the eastern and western borders of the three basins for more than 2000 miles between central Ceará and eastern Paraguay. The belt of exposures is about 600 miles wide, but along its medial part the old rocks are concealed below the Paleozoic and Mesozoic sedimentites of the basins. The Middle Precambrian rocks were very intensely folded, plutonized (i.e., metamorphosed, magmatically injected, and granitized) and apotectonically intruded during a tecto-magmatic cycle which can not be objectively correlated with any of the known Precambrian cycles of the northern hemisphere. The resulting rocks now form the Barbacena complex of Minas Gerais and Goias and its equivalents, the Gurupí Group of Maranhão and Piauí, the Ceará complex and Seridó schists of northeastern Brazil, and the Cuiabá schists of Mato Grosso and eastern Paraguay.

During Late Precambrian time, the region under consideration regained its geosynclinal characteristics, but the new geosyncline had a miomagmatic history as opposed to the pliomagmatic development of the former unit. Late Precambrian rocks, discordantly resting on the Barbacena complex, are exposed along the eastern border of the São Francisco and Paraná basins between Sergipe and Uruguay for a distance of 1800 miles. The belt is about 250 miles wide, the metamorphic rocks dipping westward below the Paleozoic and Mesozoic sedimentites of the two basins. The Late Precambrian geosynclinal trough was narrower and more sinuous than the Middle Precambrian basin, it had a more north-northeast – south-southwest trend, and its axis was located farther east-southeast. The sediments therein deposited were intensely folded but not syntectonically injected. Accordingly, the metasedimentites display a low-grade metamorphism that nowhere exceeds that of the biotite-chlorite subfacies of the greenschist facies. Apotectonic intrusions are absent in the north and scarce in the south. The Late Precambrian rocks form, at present, the Minas Group and the Itacolomí Formation of Minas Gerais, separated by a moderate discordance. Equivalents of the Minas Group are the Itabaiana Formation of Sergipe, the Jacobina Group and the Paraguassú Formation of central Bahia, the São Roque-Assunguí Group of São Paulo and Paraná, the Brusque Group of Santa Catarina, the Porongos Group of Rio Grande do Sul, and the Lascano (Minas) Group of Uruguay. Equivalents of the Itacolomí Formation seem to be the Macaúbas Formation of Minas Gerais, the Ribeira Formation of São Paulo, and the Ibirama Formation of Santa Catarina.

After the tectonic movements which compressed the geosynclinal prism and brought about its general uplift at the close of the Precambrian, the region lost forever its geosynclinal character. When, in Early Paleozoic time, renewed subsidence affected the area, three well defined basins appeared on the site of the former geosyncline. These are the Parnaíba, São Francisco, and Paraná basins which, during Paleozoic and Mesozoic time, were subjected to repeated periods of subsidence and deposition alternating with epochs of uplift and erosion. At each new period of subsidence and deposition following a period of uplift, the basins regained the general size and shape which had distinguished them during the previous sedimentary cycle. At each new period of uplift and erosion following a period of subsidence, the basins were gently raised without any important tangential compression and folding of the sediments. Moreover, it is clear that the subnegative tendency of the basins became less and less marked with the passing of time and that whereas in Early Paleozoic time the basins were repeatedly invaded by the sea, in Late Paleozoic time they were the site of continental accumulation alternating with shallow marine deposition. Since Triassic time, the sedimentary history of the basins has been exclusively continental, with transient shallow marine episodes affecting only the northern half of the Parnaíba basin at the close of the Tertiary.

It would almost look as if the "tectonic energy" of the belt interposed between the two Brazilian shields was slowly dissipated during the long evolution of the region. Eugeosynclinal in character during the Middle Precambrian, miogeosynclinal in the Late Precambrian, it ended by being basinal in the Early Paleozoic, the subnegative tendency of the region becoming less and less marked in the periods that followed.

2.2.2 Region interposed between Guiana and Central Brazilian shields. The Middle Precambrian history of this region, now occupied by the wide Amazonas basin, is totally unknown. In Late Precambrian time, however, it seems to have been the site of a lengthy miogeosyncline of general east to west direction, as strongly folded but leptometamorphosed rocks ¹intruded by apotectonic dikes and plutons (Uatumã Formation) are exposed in discontinuous patches forming two subparallel belts along the northern and southern borders of the Amazonas basin respectively.

When the region was again downwarped in ?Cambrian time, its geosynclinal nature had disappeared. Just as in the case of the region interposed between the Central and Coastal Brazilian shields, a large basin appeared on the site of the former geosynclinal trough. This was, and still is, the Amazonas basin, which underwent a sedimentary-erosional history broadly comparable with that of the Parnaíba, São Francisco, and Paraná basins. Repeatedly invaded by shallow seas in ?Cambrian, Silurian, Devonian, and Pennsylvanian time, it was the site of continental deposition during the Early Cretaceous and the Late Tertiary. At each new period of subsidence following a period of uplift and erosion, the basin regained the general shape and size which had distinguished it during the previous sedimentary cycle, but its subnegative tendency was progressively less marked. As in the case of the Parnaíba, São Francisco, and Paraná basins, no tangential compression or folding of any importance attended the periods of uplift following the periods of subsidence and sedimentation.

¹ The term is proposed here to designate rocks showing incipient to low grade metamorphism (from the Greek leptos = weak).

2.3 Pericratonic basins, nesocratons and geosynclines

2.3.1 Peripheral belt of cratonic areas. During Middle Precambrian time a geosynclinal trough extended along the northern third of the Guiana shield from northeastern Amapá in Brazil to western Bolívar in Venezuela. The trough had a general east-southeast – west-northwest trend and a length in excess of 1000 miles. It is not possible to ascertain the true width of the belt of geosynclinal rocks as only those forming its southern part are exposed at present, those of the northern section lying either below the waters of the Atlantic Ocean or concealed under the surface sediments of the Orinoco plains. The exposed rocks form a band nearly 250 miles wide and consist of metamorphosed acid and basic vulcanites associated with high-grade metasedimentites, the whole intruded by apotectonic granites. Similar rocks are known in the upper reaches of the Río Branco in Brazil and in the Pakaraima mountains of Venezuela.

In Late Precambrian time the region had once again geosynclinal characteristics. This is evidenced by the widespread occurrence of a group of leptometamorphic rocks, discordantly resting on the Middle Precambrian high metamorphics, exposed in a belt 900 miles long and 200 wide extending east-southeast – west-northwest over the same general area. The sequence is formed mainly of micaceous phyllites and quartzites devoid of syntectonic intrusions, the degree of metamorphism being comparable with that displayed by the Minas Group of Minas Gerais. In all likelihood the leptometamorphic rocks represent a marginal geosynclinal facies superimposed to the axial facies of the previous Middle Precambrian unit. This interpretation implies accepting that the axis of the Late Precambrian geosyncline had shifted away from the cratonic masses in relation to the position occupied by the axis of the Middle Precambrian trough, and that the axial belt of the latter unit lies north of the present belt of exposures of the leptometamorphic rocks.

Nothing is known about the western extremity of the Middle and Late Precambrian geosynclinal belts. In particular, it is not known whether these belts bend southwest in the State of Bolívar, following the curvature of the Guiana shield, or whether they continue with general west-northwest direction below the surface of the *llanos* in the Venezuela States of Apuré and Barinas.

Very little is known about the western border of the Central Brazilian shield facing the Beni-Chiquitos plains, but the little that is known suggests that this region, probably both during Middle and Late Precambrian time, was part of a geosynclinal belt of general northwest-southeast trend. Since Early Paleozoic time, however, the western border of the Central Brazilian shield has displayed basinal characteristics, as evidenced by the thin, discontinuous, non-metamorphosed and non-folded sequences of shallow marine Lower Paleozoic and continental Mesozoic beds exposed in the Chiquitos area.

2.3.2 Western belt of continent. The metamorphic rocks and associated intrusives of the western belt of South America pose a major problem, still very far from objective solution. Rocks of this kind are exposed in many regions between eastern Venezuela and southern Chile, forming spindle-shaped rows of comparatively narrow exposures, distant between 100 and 500 miles from the eastern cratonic masses. South of the Bolivian-Argentine border, the belt of exposures increases in width, reaches extra-Andean areas, and resolves itself into three massifs disposed *en échelon* along the southern part of the continent. The main areas of outcrop are found in the Northern Range of Trinidad, the Caribbean ranges of Venezuela, the Andes of Mérida, the Goajira peninsula, the Perijá range, the Santa Marta hills of Colombia, the Santander, Quetame, Macarena and Garzón massifs of the Eastern Cordillera of Colombia, the Central Cordillera of Colombia, the Cordillera Real of Ecuador, the Central and Eastern Cordilleras of Perú, the Paracas and Arequipa districts of the Western Cordillera of Perú, the Puna and Eastern Cordillera of northern Argentina, the Precordillera of western Argentina, the Pampean Ranges and extra-Andean Patagonia, the Patagonian Cordillera, and the Coast Cordillera of Chile as far south as Tierra del Fuego.

Nowhere more than a single group of metamorphic rocks is exposed and, more precisely, nowhere an unconformity has ever been detected within the metamorphic sequences. In some regions, as in the Caribbean ranges of Venezuela, it is certain that practically all the metamorphics (with the possible exception of the Sebastopol complex) are of Mesozoic age and as young as Cretaceous. In other regions, as in the Central Cordillera of Colombia, the bulk of the metamorphics (with the probable exception of the Mazamorras-Sibundoy complex) seems of Early Paleozoic age. Still in others, as in the Andes of Mérida, the Garzón and Macarena massifs of the Eastern Cordilleras of Colombia, and the Eastern Cordilleras and Pampean Ranges of Argentina, the Precambrian age of most of the high metamorphics seems beyond dispute. But whether all the Precambrian rocks exposed in scattered outcrops between Venezuela and southern Argentina were deposited in a continuous pericratonic geosynclinal trough during a single sedimentary cycle and were folded and plutonized during a single tecto-magmatic cycle, can not be ascertained at present.

Be that as it may, when the western regions of the continent were again downwarped and invaded by the sea in Early Paleozoic time, it is evident that the geosynclinal axes had shifted markedly away from the cratonic areas. The broad belt interposed between the eastern cratonic masses and the western geosynclinal troughs became a huge subnegative shelf or platform grading from sub-stable, sub-cratonic conditions in the east to sub-mobile, sub-geosynclinal conditions in the west. Until the final uplift of the Andean Cordilleras in Tertiary time, this broad platform — the "pericratonic basins" — was always invaded by Pacific waters progressing from west to east, the corresponding sediments becoming thinner and shallower when not grading into brackish-water and continental beds in that general direction.

As witnessed by conditions in eastern Venezuela, in the Oriente of Ecuador, in the Montaña of Perú, and in the Subandean region of southern Bolivia, to mention only the best known areas, the adcratonic belt of these basins was distinguished by a low-grade energy level of basinal characteristics (slight subnegative tendency resulting in thin, discontinuous, shallow marine to continental deposition; absence of tangential compression and folding; absence of volcanic activity) whereas the adgeosynclinal belt was characterized by a moderately high energy level of sub-geosynclinal characteristics (moderate negative tendency resulting in thicker, more continuous sequences of dominantly marine sediments; moderately strong tangential compression and folding; moderately strong volcanic activity).

Peripherally to the pericratonic basins there lies a wide mobile belt which was the site of all geosynclinal activity during post-Proterozoic time in South America.

When the Early Paleozoic geosynclines came into existence and subsidence of the new troughs was initiated, some protracted areas formed of Precambrian metamorphics remained emergent displaying a subpositive tendency which they have maintained to the present day. These persistently subpositive areas, styled "nesocratons" by the writer, are further characterized by their moderate vertical stability and by their resistance to tangential deformation.

Three of such nesocratons appeared in the southern part of the continent, arranged *en échelon* between the southern extremities of the geosynclinal troughs. The largest and most septentrional of them, the Pampean Ranges massif, is a spindle-shaped mass extending with north to south direction between Jujuy and La Pampa in Argentina for a distance of 1000 miles. The massif, which has a maximum width of 300 miles, was never covered by the sea and only occasionally, during Late Paleozoic and Triassic time, its western part became the site of continental accumulation. Though it resisted the repercussions of the Paleozoic and Mesozoic movements which affected the conterminal geosynclinal areas, it was finally broken up by Tertiary movements into numerous mountain blocks which were differentially uplifted and downfaulted. These radial displacements were attended by negligible tangential deformation.

The smaller Patagonian massif has a more northwest to southeast trend, extending from Neuquén and neighboring areas of Chile to southeastern Chubut, where it ends abruptly at the Atlantic coast. The subpositive tendency of this smaller mass was less marked than that of the Pampean Ranges massif. Accordingly, the whole region became now and again the site of continental accumulation and, more rarely, of shallow marine deposition along its peripheral areas.

The Deseado massif, even smaller than the Patagonian nesocraton, extends west-north-west – east-southeast across Santa Cruz, also ending abruptly at the Atlantic Ocean. The presence of Precambrian metamorphics at Cape Meredith in the Falkland Islands suggests that, in former days, the massif extended for a considerable distance offshore southern Patagonia. Its subpositive tendency was even less marked than that displayed by the Patagonian massif and, accordingly, the region was more often depressed and converted into a sedimentary area. Its Precambrian core, exposed in a few small localities close to the Atlantic coast, is now mostly buried below a veneer of Mesozoic and Cenozoic sedimentites and lies at depths of 2500-3000 feet below sea-level.

No nesocratons were developed in the central and northern sections of the western part of South America where the Precambrian floor of the Paleozoic and Mesozoic geosynclines was everywhere closely involved in the tectonic vicissitudes of the active belts.

The study of the evolution of the post-Proterozoic geosynclines of South America shows that no appreciable “dissipation of tectonic energy” occurred between successive cycles. Moreover, it is evident that the geosynclinal history of the southern part of the continent differs markedly from that of its northern section.

In the southern part of the continent, it is abundantly clear that a westward “migration” of the geosynclinal axis took place at the initiation of the subsidence phase of each successive geosynclinal cycle. More precisely, at the beginning of each new cycle, the axis of maximum subsidence or of maximum accumulation of the new trough — which at least in this case seem to be almost interchangeable expressions — had been displaced toward the west in relation to the position occupied by the geosynclinal axis of the previous cycle. This is beautifully illustrated by the geological features displayed in the region between the Pampean Ranges massif and the Chilean coast. Disregarding the complexities of the individual geosynclinal cycles and taking into account only the over-all picture, it is evident that here the axis of maximum subsidence and accumulation of the Early Paleozoic geosyncline run along the site of the present Precordillera, where a very thick sequence of marine Cambrian, Ordovician, Silurian, and Devonian beds was deposited. After the Acadian or Bretonian movements which finally folded and uplifted the Lower Paleozoic geosynclinal prism, the region was again downwarped in Mississippian time, but the axis of maximum depression and accumulation of the new trough had “migrated” westward and was now located along the site of the present Principal Cordillera. This is evidenced by the fact that thick marine sequences of Late Paleozoic age are exposed along the eastern foot of the Frontal Cordillera whereas farther east, in the present Precordillera, shallow marine and continental beds interdigitate. Farther east still, along the western border of the Pampean Ranges massif, only continental beds were accumulated over a peneplaned surface carved on the Precambrian rocks. The Hercynian movements which folded the Upper Paleozoic sequences were very intense in the west, where they were attended by magmatic and volcanic action, but they were very weak to almost unnoticeable along the eastern border of the geosynclinal belt. During the Mesozoic geosynclinal cycle that ensued, the axis of maximum depression was located farther west still, somewhere offshore the present coast of Chile. Again, this is evidenced by the changes of facies, degree of folding, and penecontemporaneous volcanism displayed by the Triassic, Jurassic, and Cretaceous sequences in an east to west direction.

In northern South America, particularly in Colombia and Ecuador, conditions were very different, probably because a large landmass existed west of these countries on the site of the present Galapagos-Malpelo submarine platform. It is unknown whether this area was persistently emergent during Paleozoic time or whether it underwent periodic foundering and uplifts which may have coincided or alternated with the tecto-orogenic phases of the conterminous geosynclines. It is certain, however, that at least during Late Mesozoic and Tertiary time the region was an emergent landmass which acted as a western "foreland" to the Colombian-Ecuadorian geosynclines. Its final foundering below the waters of the Pacific Ocean is a comparatively recent event which took place in Late Miocene to Early Pliocene time.

Due to the Mediterranean nature of the Colombian-Ecuadorian geosynclinal troughs, no westward "migration" of the axes took place at successive cycles. Quite on the contrary, comparable geosynclinal facies of successive cycles were superimposed one on top of the other until, in Cretaceous time, the rising of a mesial geanticlinal belt split the basin into an eastern trough of mio-magmatic character and a western trough of dominantly plio-magmatic nature.

3. PALEOGEOGRAPHIC DEVELOPMENT SINCE CAMBRIAN TIME

3.1 Cambrian

Fossiliferous Cambrian beds are extremely scarce in South America. The only known occurrences are as follows: (1) Middle Cambrian limestones exposed in a few localities in the Precordillera of western Argentina (Harrington and Lanza, 1943; Lanza, 1947; Poulsen, 1958, 1960), (2) loose limestone boulders bearing Middle Cambrian fossils, found as float in the upper reaches of the Rio Duda, Eastern Cordillera of Colombia (Harrington and Kay, 1951), and (3) Upper Cambrian limestones exposed in a single small locality west of Mendoza, in the Precordillera of western Argentina (Poulsen, 1958). The Middle Cambrian faunas are characterized by genera belonging to the so-called Pacific province of North America, with an influx of Acado-Baltic forms in late Middle Cambrian time.

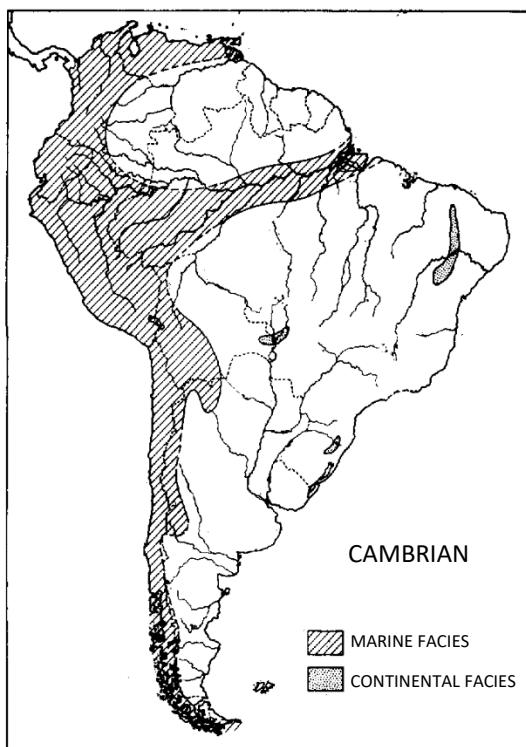


Fig. 2. – Paleogeographic map of South America. Cambrian

Non-fossiliferous beds attributed to the Cambrian crop out in other regions of the Andean belt. A thick clastic sequence exposed in the Eastern Cordilleras of northern Argentina (Keidel, 1943) and southern Bolivia (Ahlfeld and Branisa, 1960) seems unquestionably Cambrian, as it discordantly overlies much folded Precambrian metamorphics and is discordantly overlain by lowermost Tremadocian rocks. The beds thin stratigraphically and disappear southwest, south, and east of the Santa Victoria Cordillera. A moderately thick succession of black shales, anhydrite, and conglomerates recently discovered near Limbo, in the Eastern Cordillera of Bolivia east of Cochabamba (Ahlfeld and Branisa, 1960), is almost certainly Cambrian. Less certain, but quite likely, is the Cambrian age of some of the clastic formations (Ramírez, López, ?Vargas) described by Cecioni (1956) in the southern islands of the Chilean Archipelago. In addition, it seems very probable that at least a part of the metamorphics exposed in the Venezuelan Andes, the Eastern and Central Cordilleras of Colombia, the Cordillera Real of Ecuador, the Central Cordillera of Perú, and the coastal areas of southern Perú and Chile are also of Cambrian age.

No unquestionably Cambrian beds are known outside the Andean belt. Several unfossiliferous, leptometamorphic and non-metamorphic pre-Devonian formations in Brazil and elsewhere have been tentatively referred to the Cambrian by different authors. At the present moment, the writer is inclined to accept provisionally a general Cambrian age for the Jaibara Group of Ceará (Kegel et al., 1958), the Lavras and Bebedouro Formations of northern Baia (Derby, 1906; Williams, 1930), the Gaspar Formation of Santa Catarina (Freitas, 1945; Maack, 1947), and the Jacadigo Group of southern Mato Grosso (Dorr, 1945). In addition, the Acari-Jaú Formation developed in the subsurface of the middle and upper Amazonas basin (Morales, 1959) could also represent ?shallow marine to continental Cambrian deposits. The Ceará, Baia, Santa Catarina, and Mato Grosso beds seemingly represent remnants of fanglomeratic and fluviatile aprons deposited east and west of the mountain ranges which were uplifted at the close of the Precambrian along the region now occupied by the Parnaíba, São Francisco, and Paraná basins. Some beds in the upper Jacadigo (Banda Alta Formation) were probably accumulated under closed basin conditions.

The fact that Lower Tremadocian beds rest discordantly and transgressively on the Cambrian and Precambrian rocks of northern Argentina, indicates that, at least in this region, the Cambrian sedimentites were gently folded and uplifted above sea-level before the accumulation of the Lower Ordovician beds.

3.2 Ordovician

Ordovician deposits, ranging in age from earliest Tremadocian to Late Caradocian, attain great regional extension and thickness in the Andean belt. The main occurrences are as follows: (1) Tremadocian shales in the Baul area of eastern Venezuela (Rod, 1955; Frederickson, 1958), (2) Caradocian sandstones and shales in the Venezuelan Andes (Christ, 1927; Leith, 1938; Whittington, 1954; Pierce, 1960; Pierce et al., 1961), (3) Tremadocian sandstones and shales, and Arenigian and Llanvirnian graptolite shales in the Eastern Cordillera of Colombia (Trumpy, 1943; Harrington and Kay, 1951; Turner, 1960), (4) Arenigian graptolite shales in the Central Cordillera of Colombia (Harrison, 1930), (5) Caradocian graptolite shales in the Central Cordillera of Perú (Broggi, 1920; Steinmann, 1930; Lemon and Cranswick, 1956), (6) Llanvirnian shales in the Oriente of Perú (Newell and Tafur, 1944; Kummel, 1948), (7) Llanvirnian to Caradocian graptolite shales in the Central and Eastern Cordilleras of southern Perú and northern Bolivia (Wood, 1906; Bulman, 1931; Douglas, 1933; Turner, 1960), (8) Tremadocian to Caradocian beds in the Eastern Cordilleras of central and southern Bolivia and northern Argentina (Kobayashi, 1937; Harrington, 1938; Keidel, 1943; Ahlfeld, 1946; Loss, 1951; Harrington and Leanza, 1957; Ahlfeld and Branisa, 1960; Turner, 1960), (9) Arenigian to Caradocian beds in the Subandean Ranges of northern Argentina (Nieniewski and Wleklinski, 1950), (10) Tremadocian and Llanvirnian beds in the Famatina and Narvaez Ranges of northwestern Argentina (Harrington, 1938; Harrington and Leanza, 1957; Turner, 1958, 1960), (11) Arenigian graptolite shales, Llanvirnian limestones, Llandeilian graptolite shales, and Caradocian beds in the Precordillera of western Argentina (Stappenbeck, 1910; Harrington and Leanza, 1957; Furque, 1958; Turner, 1960). The rich Early Ordovician shelly faunas of South America have very strong Acado-Baltic relationships. They rapidly became impoverished and increasingly endemic during the Middle Ordovician.

No fossiliferous Ordovician beds are known south of the Precordillera of western Argentina, but some of the thick clastic formations described by Cecioni (1956) from the southern islands of the Chilean Archipelago are, in all likelihood, of Ordovician age.

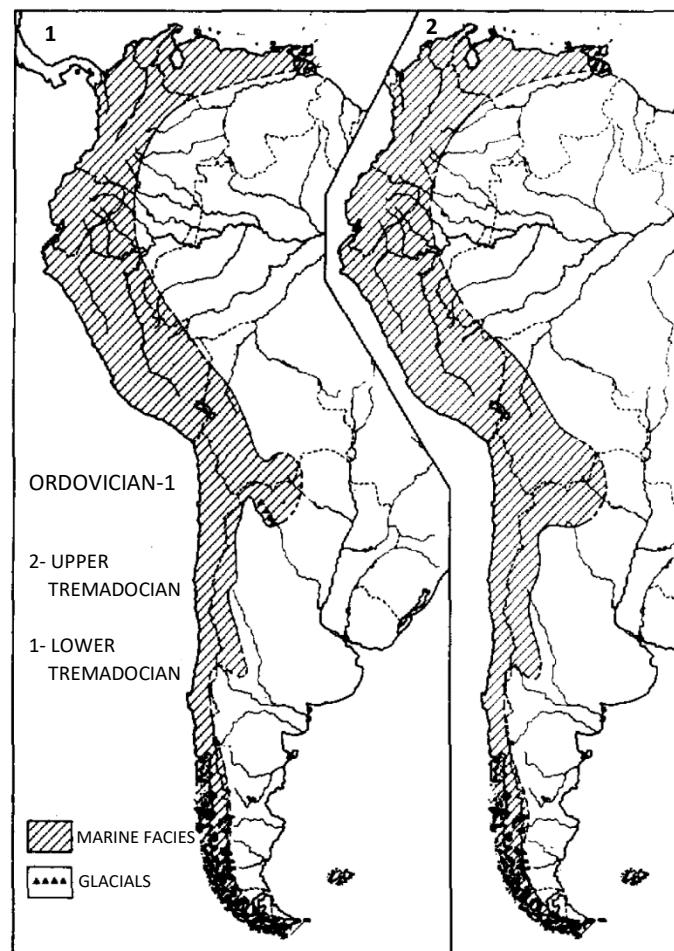


Fig. 3. – Paleogeographic maps of South America. Lower and Upper Tremadocian (Lower Ordovician).

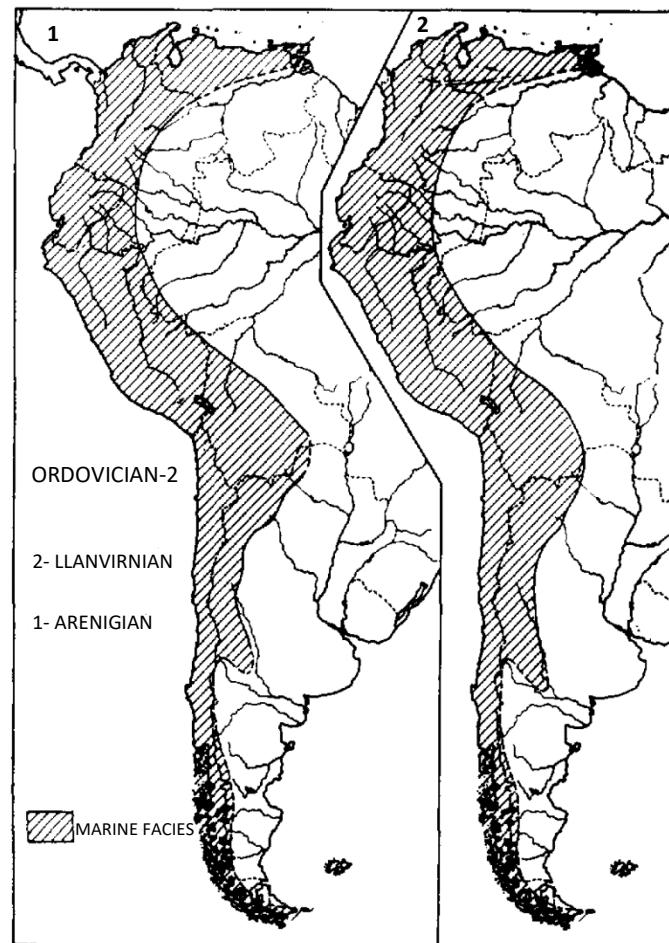


Fig. 4. – Paleogeographic maps of South America. Arenigian and Llanvirnian (Lower and Middle Ordovician)

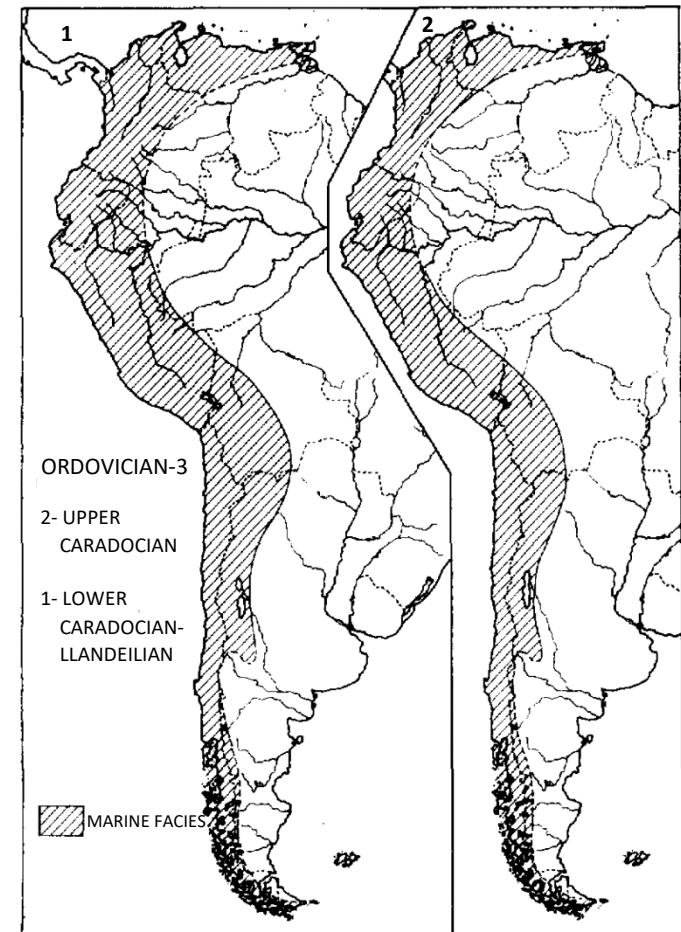


Fig. 5. – Paleogeographic maps of South America. Llandeilian and Caradocian (Upper Ordovician).

Early in the Ordovician, the sea invaded the western belt of the continent overflowing the region previously flooded by the Cambrian waters. The transgression progressed rapidly eastward across the Chaco region, but apparently it did not reach the western border of the Central Brazilian shield. The Arará-Corumbá-Bodoquena-Itapucumí Formations, exposed in southern Mato Grosso (Evans, 1894; Oliveira and Moura, 1944; Almeida, 1945; Beurlen and Sommer, 1957; Maciel, 1959), eastern Bolivia (Barbosa, 1949, 1957), and eastern Paraguay (Harrington, 1950; Eckel, 1959; Putzer, 1962), previously regarded as Lower Paleozoic, are very probably Late Precambrian in age (G. A. Chamot, private communication).

In Middle Tremadocian time local glaciers appeared along the northern plunge of the Pampean Ranges massif, which formed a protruding cape separating the Jujuy embayment on the east from the main geosynclinal trough on the west (Keidel, 1943; Harrington and Leanza, 1957). The glaciation was short-lived and the ice disappeared in the early Late Tremadocian.

The Ordovician transgression reached maximum expansion during Late Arenigian to Early Llanvirnian time. By Late Llanvirnian time a general regression was in progress and, during the remainder of the Ordovician, the eastern shore of the Andean trough shifted steadily toward the west.

The Ordovician sedimentary cycle ended in Late Caradocian, or possibly in Early Ashgillian time, with a general uplift of the geosynclinal prisms which in some areas, as in southern Bolivia and the Precordillera of western Argentina, was assisted by faulting and tilting. In western Argentina, these movements were preceded in Llandeilian time by differential uplifts along the eastern border of the basin (Furque, 1958).

3.3 Silurian

During Early Silurian time most of the Andean region remained uplifted above sea-level, with the probable exception of a wide “sea portal” across Ecuador and the northern half of Perú. Extensive extra-Andean areas, on the other hand, were flooded early in the period. Lower Silurian (Valentian) fossiliferous beds are known along the northern and southern borders and in the subsurface of the Amazonas basin (Trombetas Formation: Moura, 1938; Morales, 1959), in the Chiquitos region of eastern Bolivia (Carmen sandstones: Barbosa, 1949; Lange, 1955), and along the western border of the Paraná basin in eastern Paraguay (Caacupé Group: Harrington, 1950; Eckel, 1959; Wolfart, 1961; Putzer, 1962). The close similarity between the Trombetas and Caacupé faunas indicate a free marine communication between the Amazonian and Paraguayan regions along the Beni-Chiquitos pericratonic belt. The Lower Silurian sea seems to have extended south of Paraguay into eastern Argentina and possibly also into southern Uruguay. Here, the Curamalal Group of the southern hills of Buenos Aires (Harrington, 1947) is almost certainly Lower Silurian, whereas the Balcarce quartzites (Nágera, 1919; Tapia, 1937, 1938) and the Punta Mogotes shales (Tapia, 1937) of the northern hills of Buenos Aires very likely belong in this epoch. The Early Silurian age of the Polanco limestones of Uruguay (Goñi, 1958), however, is considerably more problematic.

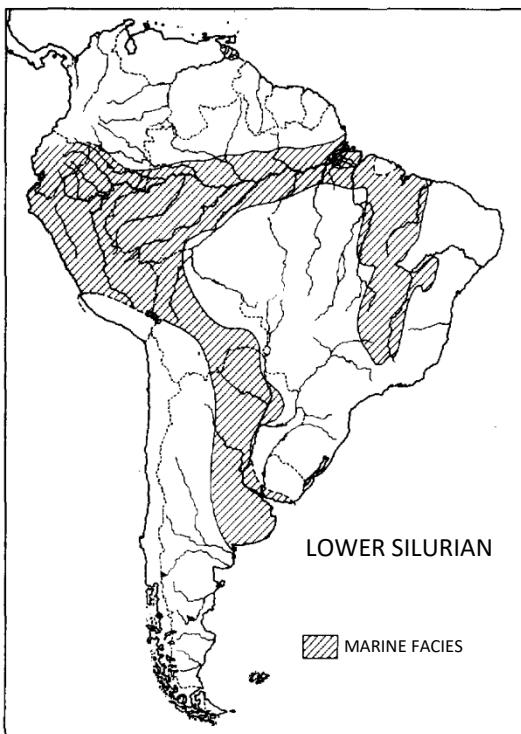


Fig. 6. – Paleogeographic map of South America. Lower Silurian

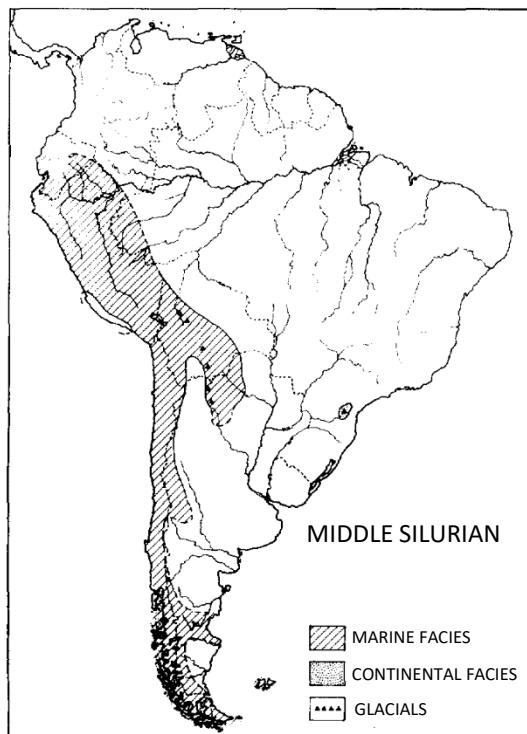


Fig. 7. – Paleogeographic map of South America. Middle Silurian

Lower Silurian seas seem to have invaded also the São Francisco, Salitre, and Parnaíba basins of northeastern Brazil. The Bambuí Group of the São Francisco basin (Freyberg, 1932; Barbosa and Oppenheim, 1937; Penna Scorza, 1942), formed of arkoses, sandstones, shales, and limestones, is probably Silurian as believed by Derby (1880) and Ruedemann (1929). The Salitre limestones of the Salitre-Rio Verde basin of northwestern Baia (Mello Junior, 1938; Oliveira and Leonardos, 1943), and the Una limestones of the eastern foot of the Serra do Sincorá in central Baia (Williams, 1930) are best regarded as lateral extensions of the Bambuí Group. In the Parnaíba basin, Bambuí limestones crop out below Lower Devonian rocks in southeastern Piauí (Kegel, 1956) and western Ceará (Kegel et al., 1958), whereas exposures of Silurian rocks have been mentioned by Oddone (1953) near Alcobaça on the Rio Tocantins, along western Maranhão.

During Middle Silurian time the sea abandoned the extra-Andean basins at a time when the Andean geosynclinal troughs were being downwarped and invaded by the Pacific waters. The coastal region of southwestern Perú, however, seems to have remained emergent. Fossiliferous Middle Silurian (Wenlockian) beds are known in the Eastern Cordillera of southern Perú (Balta, 1898), the Central and Eastern Cordilleras of Bolivia (Douglas, 1920; Kozlowski, 1923; Alhfeld and Branisa, 1960), the Subandean Ranges of Bolivia (Padula and Reyes, 1958) and northern Argentina (Nieniewski and Wleklinski, 1950; Ruiz Huidobro, 1955), and the Precordillera of western Argentina (Clarke, 1912; Keidel, 1921; Leanza, 1950; Castellaro, 1959). In Bolivia and Argentina the Wenlockian beds rest discordantly on Ordovician rocks. No Silurian strata have been recognized in the Cordilleran areas south of Mendoza in Argentina and north of Sicuani in Perú. It seems likely, however, that some of the Lower Paleozoic clastic formations described by Cecioni (1956) from the southern islands of the Chilean Archipelago are of Silurian age, whereas the "ten kilometers thick" sequence of Devonian rocks described by Heim (1948) from the eastern slope of the Cordillera de Vilcabamba in southern Perú probably includes Silurian beds. Part of the comprehensive "Excelsior Group" of McLaughlin (1924), exposed between Tarma and Cerro de Pasco in the Central Cordillera of Perú, may also be of Silurian age.

The base of the Wenlockian sequence in northern Argentina and Bolivia is marked by a persistent glacial-marine conglomerate, the so-called “Zapla tillite” (Schlagintweit, 1943), indicating a localized and short-lived glaciation. The continental Iapó Formation of eastern Paraná (Maack, 1947; Caster, 1952), if truly glacial and truly Silurian (which is still far from proved) could indicate a synchronous localized glaciation in eastern Brazil.

No upper Silurian rocks are known in South America. The “upper” Silurian age of the Argentine Middle Silurian was the result of a misunderstanding arising from the expression “Upper Silurian” used by Clarke (1912) in the German sense, when referring to the Precordilleran fossils, and interpreted as Upper Silurian in the American sense by the German geologists then working in Argentina.

By the end of the Middle Silurian the Andean troughs were abandoned by the sea as the result of a general uplift which was not assisted by folding. Caledonian movements were extremely mild in South America, resulting in gentle regional unconformities.

3.4 Devonian

No Helderbergian rocks are known in South America, the Devonian sedimentary cycle beginning with Upper Ulsterian strata. Beds of this age attain great thickness and regional development in the Andean belt between the Eastern Cordillera of Ecuador and the Patagonian Cordillera, and are also widespread in the extra-Andean basins. No lower Devonian beds are known in Venezuela and Colombia, which probably remained emergent during this epoch.

Though no diagnostic fossils have been found in Ecuador, it seems likely that the Margajitas Formation (Tschopp, 1948) of the eastern border of the Cordillera Real, and the Pumbuiza Formation (Tschopp, 1953) of the Cutucú hills belong in the Lower Devonian. Fossiliferous Lower Devonian beds are known in the Central Cordillera of central Perú (Harrison, 1943, 1951) and southern Perú (Douglas, 1920; Heim, 1948; Newell, 1949), in the Paracas region of southwestern Perú (Newell et al., 1953), the Central and Eastern Cordilleras of Bolivia (Steinmann and Hoek, 1912; Kozlowski, 1923; Swartz, 1925; Ahlfeld and Branisa, 1960), the Coipasa area of the Western Cordillera of Bolivia (Swartz, 1925), the Subandean Ranges of Bolivia (Mather, 1922; Padula, 1956; Ahlfeld and Branisa, 1960) and Argentina (Feruglio, 1930; Schlagintweit, 1937; Arigós and Vilela, 1949; Nieniewski and Wleklinski, 1950; Ruiz Huidobro, 1955), the Precordillera of western Argentina (Keidel, 1921; Bracaccini, 1946; Heim, 1952; Frenguelli, 1951; Furque, 1956), the Chilean coast in the Province of Coquimbo (Muñoz Cristi, 1942), the Sierra Pintada of southern Mendoza (Dessanti, 1945; Padula, 1951), and the Lago Pueyrrendón area in the Patagonian Cordillera (Feruglio, 1949).

In the extra-Andean regions. Lower Devonian beds are extensively developed in the Amazonas basin (Moura, 1938; Morales, 1959), the Parnaíba basin (Kegel, 1953, 1957), the Paraná basin of eastern Brazil (Maack, 1946; Caster and Petri, 1947; Petri, 1948; Sanford and Lange, 1960), Mato Grosso (Almeida, 1948; Caster, 1952), Paraguay (Harrington, 1950; Eckel, 1959), and Uruguay (Méndez Alzola, 1938; Lambert, 1941), the Chiquitos region of eastern Bolivia (Barbosa 1949), the subsurface of the Paraguayan Chaco (Eckel, 1959), the southern hills of Buenos Aires in eastern Argentina (Harrington, 1947), and the Falkland Islands (Baker, 1923; Adie, 1952). In addition, the Sierra Grande formation of northeastern Chubut, north of Puerto Madryn in Patagonia, is almost certainly Lower Devonian. Both the Andean and the extra-Andean Lower Devonian beds are characterized by a peculiar “austral” fauna (Clarke, 1913) not directly comparable with northern hemisphere assemblages.

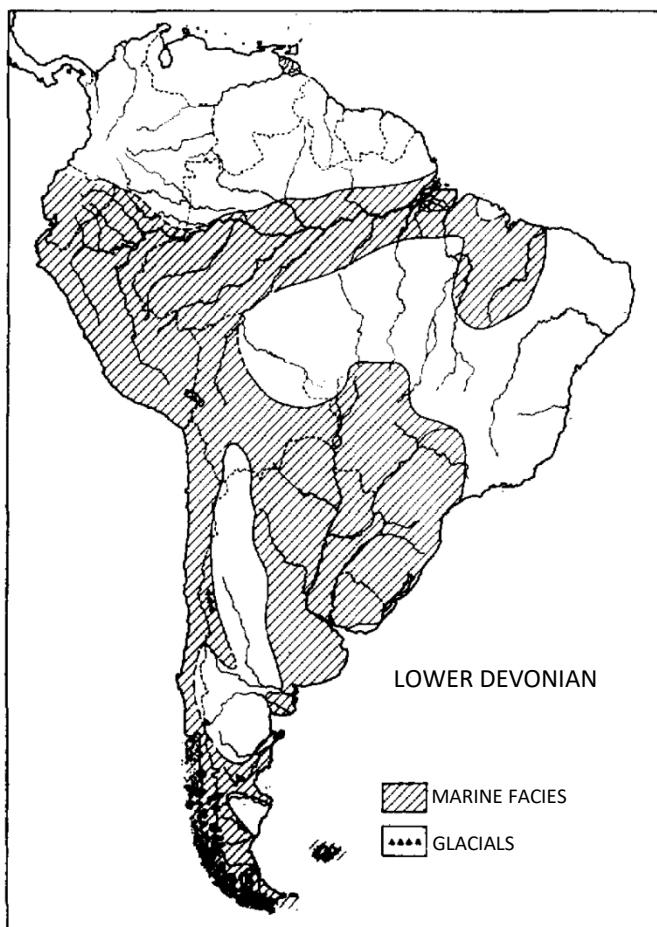


Fig. 8. – Paleogeographic map of South America.
Lower Devonian

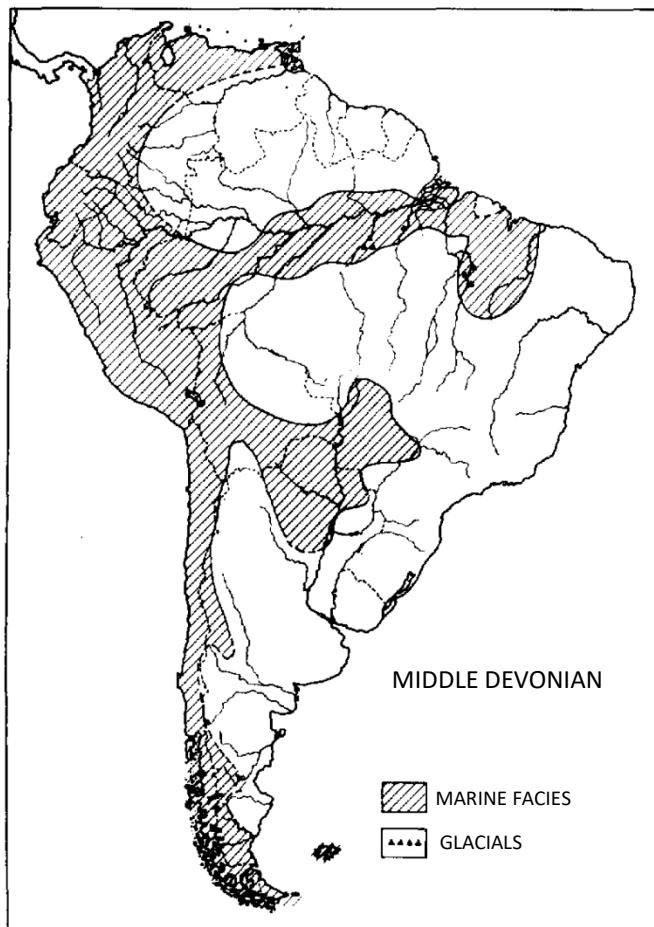


Fig. 9. – Paleogeographic map of South America.
Middle Devonian

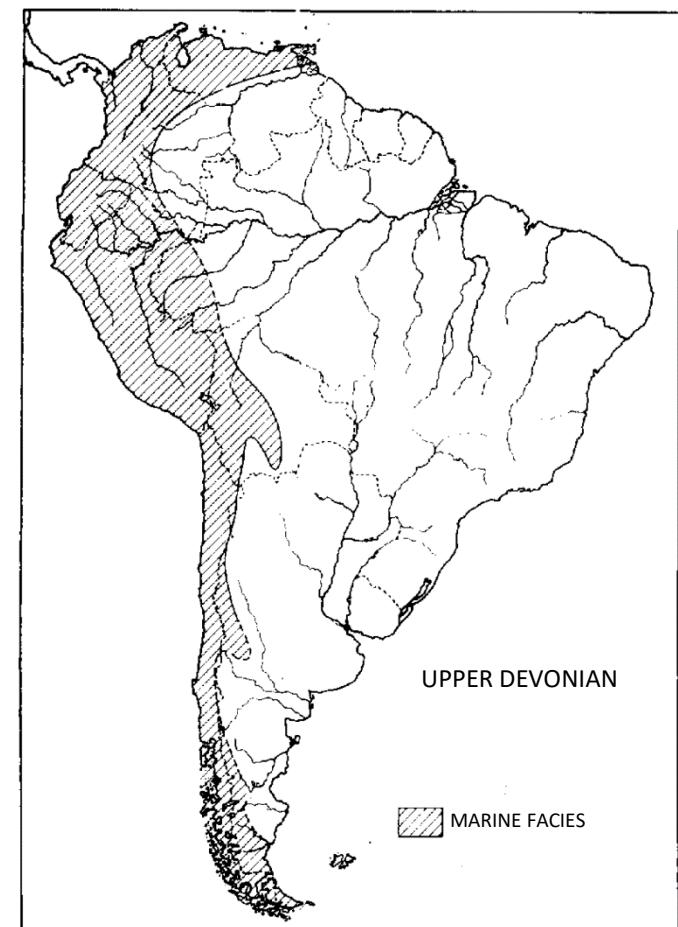


Fig. 10. – Paleogeographic map of South America.
Upper Devonian

Sometime during the Early Devonian local glaciers appeared along the western flank of the Pampean Ranges massif of west-central Argentina, discharging into the Precordilleran basin where glacial-marine conglomerates were intercalated in the sequence 3000 feet above its base. Similar beds are known in the middle part of the Lower Devonian succession of the Falkland Islands.

At the beginning of the Middle Devonian the sea abandoned the southern extra-Andean areas and most of the Paraná basin. Here, however, the regression seems to have been incomplete, the sea remaining in the Mato Grosso-Goias depression (Caster, 1952) and probably also in the western part of the Altos-Ponta Grossa depression as the transverse Bodoquena-São Paulo and San Juan Bautista-Torres archs began to rise across the Paraná basin. This partial regression was compensated by the subsidence of the Colombian-Venezuelan Andean troughs which were flooded in Early Erian time. Middle Devonian fossiliferous beds are known in the Eastern Cordillera of Colombia (Caster, 1939, 1952; McNair, 1940), the Perijá Range of Colombia (Trumpy, 1943) and Venezuela (Liddle et al., 1946), the Guajira peninsula (Bürgl, 1958), and the Venezuelan Andes (Liddle, 1946; Pierce, 1956, 1960; Pierce et al., 1961). Both in the Eastern Cordillera of Colombia (Floresta) and in the Perijá Range, the Middle Devonian beds rest directly on metamorphic rocks. In the Andean belt between Perú and Argentina, as well as in the Amazonas, Parnaíba, and western Paraná basins, the Early Devonian sedimentary cycle continued without interruption into the Middle Devonian. Both in the Andean and in the extra-Andean areas the beds are characterized by a mixed "boreal" and "austral" fauna which becomes more closely allied to North American congeries as the northern extremity of the continent is approached.

A second localized glaciation occurred during Middle Devonian time. Glaciers appeared in the northeastern extremity of the Central Brazilian shield, discharging both into the Amazonas and the Parnaíba basins, where glacial-marine conglomerates are interbedded in the dominantly marine sequences (Moura, 1938; Kegel, 1953, 1957).

In Late Devonian time the sea withdrew from all the extra-Andean regions, but seems to have persisted in the Andean belt. The great total thickness of the Devonian succession in western Venezuela, southern Perú, central Bolivia, and western Argentina suggests that, at least in these areas, the upper barren beds belong in the Upper Devonian.

Sometime during the Late Devonian the Andean geosynclinal troughs were compressed and uplifted above sea level. Folding was extremely intense in the south, but moderate to weak north of Bolivia. The repercussion of these movements in the extra-Andean regions accelerated the uplift of several archs which had been slowly rising since Middle Devonian time across the Amazonas and Paraná basins. The absence of Devonian beds in the subsurface of the Iquitos, Purus, Parintins, and Gurupá archs (Morales, 1959) across the Amazonas basin, and apparently also in the Bodoquena-São Paulo and San Juan Bautista-Torres archs across the Paraná basin, is due to uplift and erosion prior to the accumulation of Upper Paleozoic strata.

3.5 Mississippian

The Mississippian was essentially a geographic period in South America. Beds of this age are scarce in the Andean region north of Perú, being known only in the Eastern Cordillera of Colombia between western Caquetá and Cundinamarca. They begin with continental deposits (Pipiral beds) bearing plant remains (Schuchert, 1935; Kehrer, 1936) succeeded by marine limestones and shales (Gachalá Formation) containing Meramecian to Chesterian fossils (Royo y Gómez, 1945; Weeks, 1947).

Continental Mississippian sedimentites with intercalated volcanic tuffs are known in the Central Cordillera of Perú (Newell et al., 1953). Similar beds are known in the Paracas peninsula (Rüegg, 1952, 1957; Petersen, 1954) where they bear plant remains (Berry, 1922; Seward, 1922; Gothan, 1927; Read, 1941; Jongmans, 1954). Doubtful exposures are mentioned from the Paita region south of Talara (Steinmann, 1929), and from Lake Titicaca (Newell et al., 1953; Ahlfeld and Branisa, 1960). Mississippian marine fossils were mentioned by Douglas (1920) from the region north of the Titicaca, but the remains are in all likelihood Pennsylvanian.

Mississippian tillites and glacio-fluviatile deposits (Tupambi Formation) are known in the Subandean region of Bolivia and northern Argentina (Arigós and Vilela, 1949; Mauri et al., 1956; Chamot, 1960). The age of these beds has been recently established through pollen analysis.

Continental beds, characterized by a *Rhacopteris* flora, are widespread in the western Pampean Ranges of Argentina (Frenguelli, 1944, 1946; Heim, 1948) and in the eastern Precordillera, where they contain a few marine and brackish-water intercalations (Leanza, 1948; Amos, 1954; Furque, 1958). In the Famatina and Narvaez Ranges the accumulation of continental clastics was preceded by the extrusion of rhyodacites (Turner, 1958). In the western Precordillera, the Mississippian sequence is dominantly marine and bears a *Septosyringothyris* fauna of close North American affinities (Keidel and Harrington, 1938; Zöllner, 1950, Mésigos, 1953). The marine beds extend southward into the upper Rio Tunuyán district of the Frontal Cordillera (Polanski, 1958; Fidalgo, 1959), the Sierra Pintada of southern Mendoza (Dessanti, 1945; Amos, 1957), and the Cordillera del Viento of Neuquén (Zöllner and Amos, 1955). In the Cordillera del Viento, the dominantly marine sequence contains *Rhacopteris*-bearing intercalations and rests discordantly on older Mississippian rhyolitic flows and tuffs. The southernmost known exposures of marine Mississippian beds are found in the Tepuel-Languíñeо region of western Chubut (Suero, 1953, 1958; Amos, 1958; Amos et al., 1960).

During Mississippian time, Alpine glaciers appeared in the Precordilleran area of western Argentina, where a mountain range had been uplifted at the close of the Devonian. Both tillites and glacio-marine conglomerates are found intercalated between the continental and marine beds of the Precordillera and of the western Pampean Ranges. Similar glacial beds are known in the Subandean region of Bolivia and northern Argentina, in the Cordillera del Viento, and in western Chubut, indicating the synchronous appearance of several glaciation centers.

Outside western South America, Mississippian beds are known only in the Parnaíba basin, where they are represented by the Potí Formation bearing plant remains (Dolianti, 1954) and marine pelecypods (Kegel, 1955).

At the close of the Mississippian, or maybe in Early Pennsylvanian time, tectonic movements took place in the Andean belt. They were strong in western Argentina, but moderate to weak elsewhere.

3.6 Pennsylvanian

No fossiliferous Lower Pennsylvanian rocks are known in South America, with the possible exception of fusulinid-bearing limestones of doubtful Atokan age exposed in a single locality in the southern Chilean Archipelago (Cecioni, 1956).

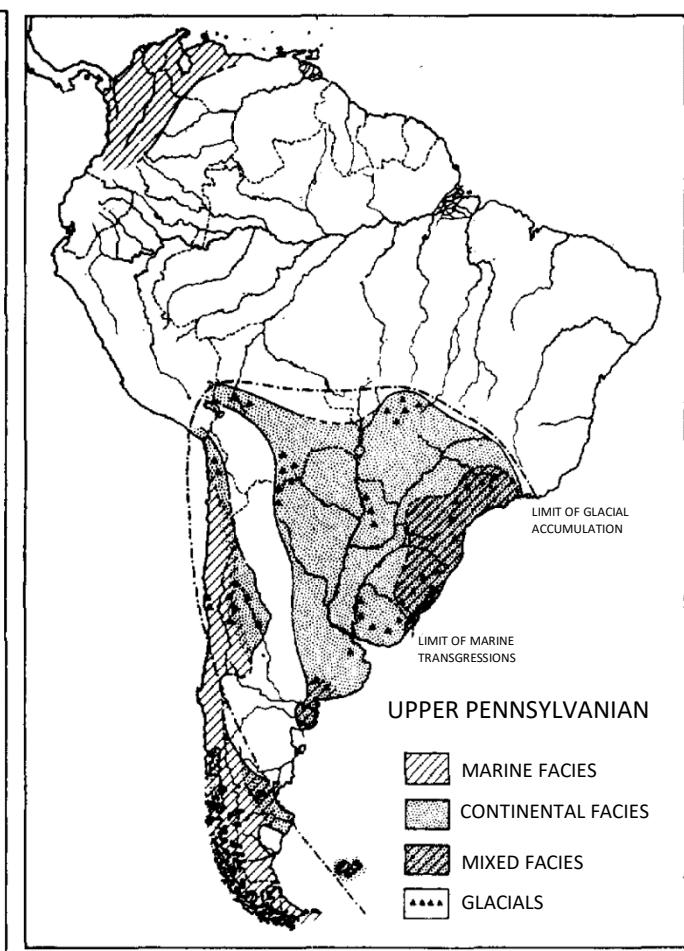
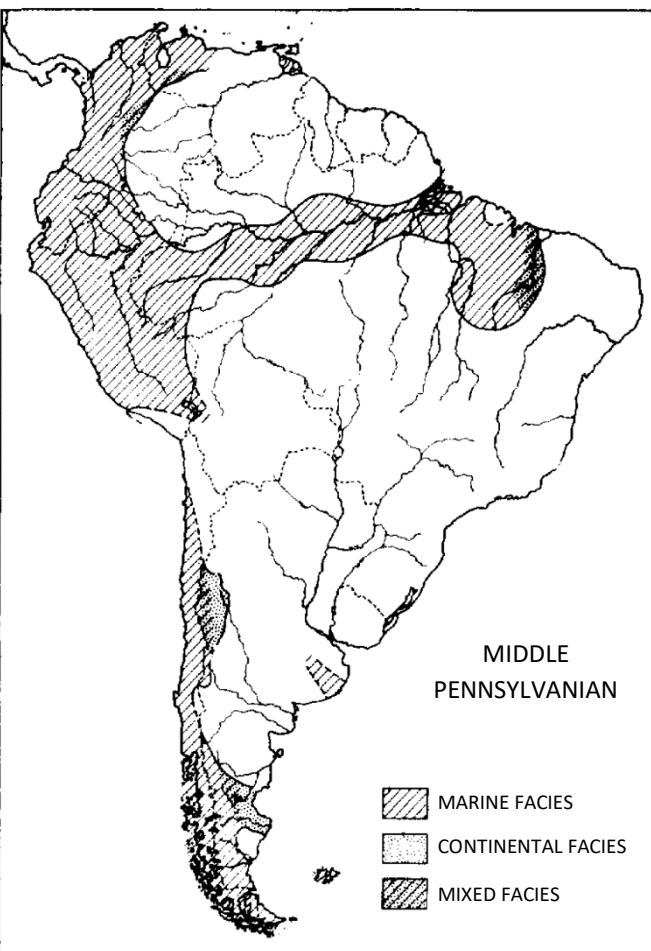
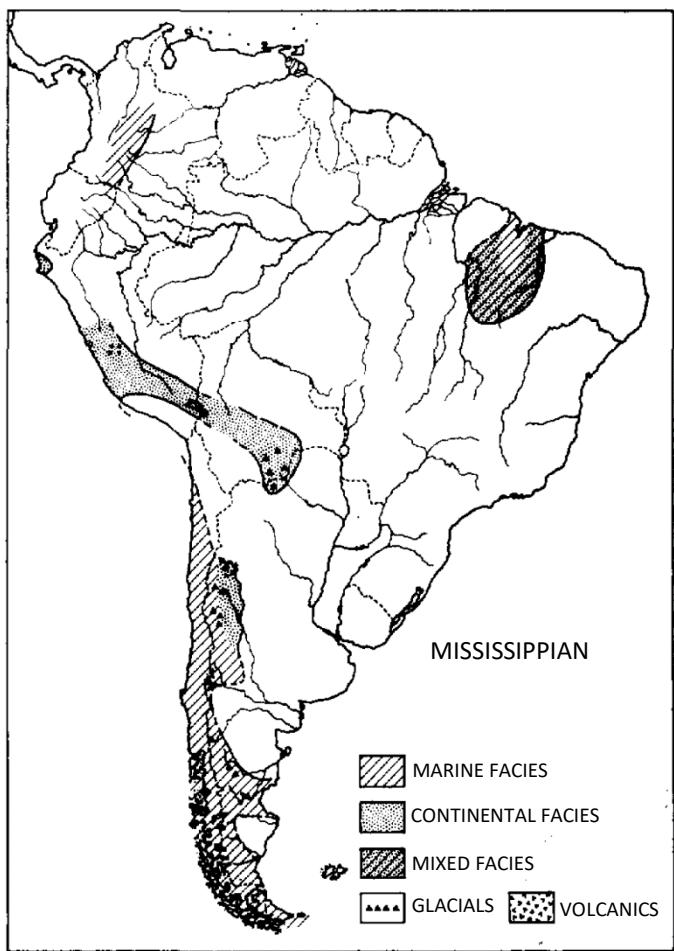


Fig. 11. – Paleogeographic map of South America.
Mississippian

Fig. 12. – Paleogeographic map of South America.
Middle Pennsylvanian

Fig. 13. – Paleogeographic map of South America.
Upper Pennsylvanian

In Middle Pennsylvanian time the sea invaded large areas of the northern part of the continent, both Andean and extra-Andean. In the region now occupied by the Venezuelan Andes, however, accumulation began with continental beds (Sabaneta Formation), succeeded in late Middle Pennsylvanian time by marine deposits (lower Palmarito Formation) (Dickey, 1941; Trumpy, 1943; Pierce et al., 1961). In the Eastern Cordillera of Colombia, the Pennsylvanian is represented by marine limestones. Pennsylvanian limestones and shales (Macuma Formation) are known in the Cutucú Range of eastern Ecuador (Tschopp, 1953), and in the Oriente of Perú, where they bear Desmoinesian fusulinids (Kummel, 1948). The same calcareous facies (Tarma Group) is developed in the Central Cordillera as far south as Muñani near Lake Titicaca (Newell et al., 1953), and apparently extends to the Camaná area on the southwestern coast of Perú (Rüegg, 1957). In the Amotape-Paita region of northwestern Perú, the Middle Pennsylvanian displays a sandy facies (Amotape Formation) (Thomas, 1930; Quiroga and Petersen, 1954).

Outside the Andean region, Middle Pennsylvanian sandstones, limestones, shales, and evaporites (Monte Alegre, Itaituba, and Nova Olinda Formations) are widespread in the Amazonas basin (Kegel, 1951; Petri, 1952; Caster, 1954; Dresser, 1954; Camargo Mendes, 1956; Morales, 1959) and in the Parnaíba basin (Piauí Formation) where they contain continental intercalations (Campbell, 1950; Kegel, 1951, 1953, 1958; Link, 1959).

Sedimentary conditions in southern South America during Middle Pennsylvanian time were similar to those prevailing in the Mississippian, though, apparently, no glacial deposits were accumulated. Continental beds, bearing a cosmopolitan flora, were deposited in isolated basins along the western flank of the Pampean Ranges and in the Precordillera (Frenguelli, 1946; Bracaccini, 1946; Heim, 1946; Furque, 1958), whereas marine beds accumulated on what is now the eastern foot of the Frontal Cordillera of Mendoza (Polanski, 1958; Fidalgo, 1959). Farther south, the upper section of the Tepuel Group of western Chubut (Suero, 1958) contains abundant marine fossils of Middle Pennsylvanian age, including goniatites (Miller and Garner, 1953; Miller and Furnish, 1958), whereas the lower part of the Eleuterio Formation of the southern Chilean Archipelago bears Desmoinesian fusulinids (Cecioni, 1956). An isolated occurrence of ?Middle Pennsylvanian beds is known in the northern hills of Buenos Aires, eastern Argentina (Harrington, 1940; Gonzalez Bonorino, 1954).

In Late Pennsylvanian time a general regression was felt in the northern part of the continent, the sea abandoning the Parnaíba, Amazonas, and Peruvian basins: only the Andean belt of Colombia and Venezuela, which had been flooded late in the Middle Pennsylvanian, remained submerged. In the southern part of the continent, on the other hand, dominantly continental "Lower Gondwana" beds were deposited, characterized almost everywhere by thick glacial conglomerates near their base and an early *Glossopteris* flora. The glaciation had continental proportions, true tillites being widespread over very extensive areas. Thick glacial conglomerates are known in southeastern Brazil (Almeida, 1952), Uruguay (Lambert, 1941), Mato Grosso (Almeida, 1948), Paraguay (Eckel, 1959; Putzer, 1962), the Subandean Ranges of Bolivia and northern Argentina (Arigós and Vilela, 1949; Padula, 1956; Díaz, 1959; Ahlfeld and Branisa, 1960; Chamot, 1960), the Juan de Morales region east of Iquique in northern Chile (Galli, 1956, 1957), the western Pampean Ranges and the Precordillera of western Argentina (Zöllner, 1950; Mésigos, 1953), the coastal area of central Chile (Fuenzalida, 1938; Muñoz Cristi, 1942; Hoffstetter et al., 1957), the subsurface of the Salado graben south of Buenos Aires city, the southern hills of Buenos Aires Province (Harrington, 1947; Suero, 1957), and the Falkland Islands (Baker, 1923; Adie, 1952). Usually, several successive tillites are present in each area, separated by more or less thick interglacial beds which, in southeastern Brazil, the Precordillera, and the Pampean Ranges, bear an early *Glossopteris* flora with *Gondwanidium*, *Pecopteris*, and *Sphenopteris*.

In southeastern Brazil, the dominantly glacial-continental Upper Pennsylvanian sequence contains at least three thin marine intercalations bearing endemic assemblages (Capivarí, Taió-Mafra, and Passinho faunules) of doubtful Australian affinities (Almeida and Barbosa, 1953; Kegel, 1951; Almeida, 1952; Martins, 1952; Maack, 1952; Camargo Mendes, 1952; Kegel and Teixeira, 1951; Lange, 1954; Sanford and Lange, 1960). They represent short-lived transgressions which apparently flooded only the eastern half of the Paraná basin.

In the western Precordillera of Argentina, the sequence is dominantly marine: its lower part bears thick intercalations of glacio-marine conglomerates, whereas its middle section contains a Tethyan fauna (Mésigos, 1953). Similar marine beds related to glacio-marine conglomerates are known in central Chile (Fuenzalida, 1938). In the southern hills of Buenos Aires, the sequence begins with true continental tillites succeeded by alternating marine sandstones and glacio-marine conglomerates (Harrington, 1947).

In western Chubut, the Upper Pennsylvanian consists of continental beds (Nueva Lubecka Group) bearing an early *Glossopteris-Pecopteris-Sphenopteris* flora, with fossiliferous marine intercalations (Feruglio, 1951; Frenguelli, 1953; Suero, 1958). Continental beds, bearing a similar flora, are also developed west of Bahía Laura in eastern Santa Cruz (Suero and Criado Roque, 1955). No glacial deposits are known in the Patagonian successions.

Lastly, the middle part of the Eleuterio Formation of the southern Chilean Archipelago bears Missourian and Virgilian fusulinids (Cecioni, 1956).

3.7 Permian

During Early Permian time, the northern Andean troughs regained much the same characteristics which had distinguished them in the Middle Pennsylvanian. In the Venezuelan Andes, beds of this age are represented by the bulk of the Palmarito Formation, bearing Wolfcampian and Leonardian fusulinids (Kehrer, 1938; Liddle, 1946; Pierce, 1960; Pierce et al., 1961). Similar limestones are known in the Venezuelan flank of the Perijá Range (Liddle, 1946) and in the Guajira peninsula (Stutzer, 1934), whereas limestones bearing Wolfcampian and Leonardian fusulinids are exposed in the Colombian flank of the Perijá (Trumpy, 1943; Thompson and Miller, 1949). No Permian beds have been identified as such in southern Colombia and Ecuador, but they reappear in Perú where they are extensively developed in a dominantly calcareous facies (Copacabana Group) along the Central Cordillera between Leimebamba and Lake Titicaca (Newell et al., 1953). These beds, bearing the well-known *Neospirifer condor-Linoprotuctus cora* fauna, extend farther south in isolated patches along the Central Cordillera of Bolivia to the vicinity of Tarija (Kozlowski, 1914; Branisa, 1958; Ahlfeld and Branisa, 1960) and are also known in the northern Subandean Ranges (Díaz, 1959) and in northern Chile east of Iquique (Galli, 1957; Hoffstetter et al., 1957). The *Dadoxylon*-bearing Toco Formation east of Tocopilla (Harrington, 1961) could also belong in the Lower Permian. The fusulinid-bearing limestones in the subsurface of the Ganso Azul area in the Oriente of Perú (Thompson, 1943) seemingly constitute an extension of these beds. In the southern Subandean Ranges of Bolivia, the Lower Permian is represented by the thin Taiguati Formation bearing *Linoprotuctus cora* (Chamot, 1960). In central Chile (Aconcagua and Coquimbo Provinces), the Lower Permian seems to be represented by the Huéntelauquen Formation, bearing marine fossils (Fuenzalida, 1940; Muñoz Cristi, 1942; Hoffstetter et al., 1957).

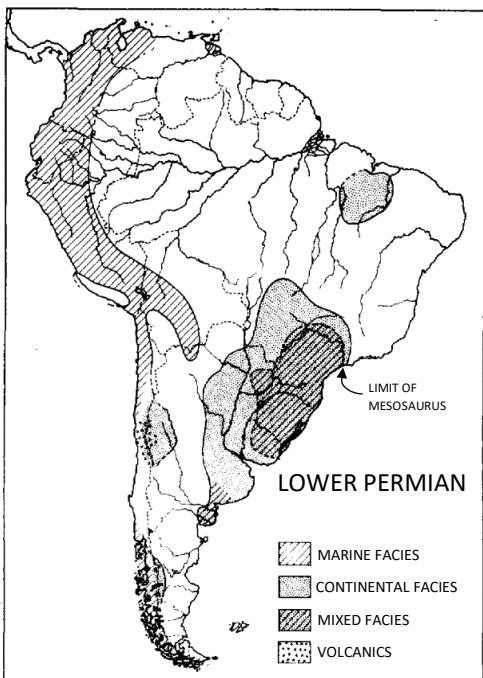


Fig. 14. – Paleogeographic map of South America. Lower Permian

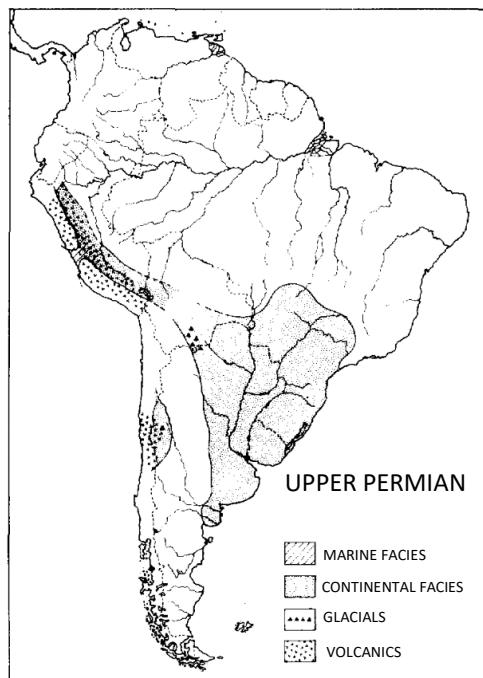


Fig. 15. – Paleogeographic map of South America. Upper Permian

In Early Permian time a general amelioration of the climate in the southern part of South America brought about the end of the continental glaciation. The sedimentary basins remained much the same as during Late Pennsylvanian time, but the Parnaíba basin was added as the site of continental accumulation (Price, 1948; Campbell, 1950; Link, 1959). In the Paraná basin continental beds were deposited, with a thin marine intercalation (Iratí black shales) bearing *Mesosaurus* remains (Almeida, 1952). In the southern hills of Buenos Aires, the Lower Permian is represented by marine shales succeeded by alternating marine and continental beds bearing an Australian *Eurydesma* fauna and a "pure" *Glossoptris* flora (Harrington, 1947, 1955).

No Lower Permian beds have been recognized in the Precordillera of western Argentina or, apparently, in the Pampean Ranges. In Patagonia, the upper beds of the continental Nueva Lubecka Group of western Chubut (Suero, 1958) may belong in the Lower Permian. Farther south, in the Chilean Archipelago, the upper part of the Eleuterio Formation bears Wolfcampian fusulinids (Cecioni, 1956; Hoffstetter et al., 1957).

The Late Permian was essentially a geocratic epoch. Though the sea may have lingered in the northern Andean troughs until the Early Guadalupian, by Middle Guadalupian time a general regression was felt, probably related to tectonic movements which were particularly intense along the Peruvian coastal belt. Continental red beds (Mitu Formation), with abundant pyroclastic material originated in volcanic centers located along this belt, were accumulated in the Central Cordillera of Perú between Leimebamba and Lake Titicaca (Newell et al., 1953). In the Tarma region the redbeds contain thin marine intercalations and this suggests that the sea was able to cross the rising volcanic belt which, at least during the initial tectonic phase, must have been a row of volcanic islands. It is likely that some of the redbeds grouped with the La Quinta and Girón Formations in Colombia and Venezuela, respectively, are of pre-Triassic age and represent a northern extension of the Mitu Formation. In the Subandean Ranges of Bolivia and northern Argentina, the Upper Permian is represented by the continental Escarpment and San Telmo Formations, bearing Tartarian (Ochoan) estheriids. These beds contain intercalations of glacial and glacio-fluviatile conglomerates indicating the appearance of Alpine-type glaciers in the rising mountains to the west.

In the Precordillera of western Argentina, the upper Permian is represented by the continental Santa Clara Group exposed along the eastern border of the range north of Mendoza. These beds bear a late *Glossopteris* flora, a thin glacial intercalation, and thick interbeds of rhyolitic and andesitic tuffs probably derived from volcanic eruptions farther west (D. Nesosi, unpublished thesis; Harrington, unpublished report).

In the Paraná basin, eolian and fluviatile deposits, were accumulated with thin but very widespread lacustrine intercalations bearing a rich fresh- to brackish-water pelecypod fauna derived from the Upper Pennsylvanian marine stocks (Leanza, 1948; Camargo Mendes, 1945; Harrington, 1950; Almeida, 1952).

3.8 Triassic

As a consequence of the orogenetic uplifts which closed the Hercynian diastrophic cycle, practically the whole of South America remained emergent during the Early and Middle Triassic. Very little is known about the sedimentary history of the continent during this time, as Lower and Middle Triassic rocks have been identified only in small areas of western Argentina and central Chile: the so-called Ladinian beds of Acrotambo in central Perú (Körner, 1937) are in all probability Norian (Jenks, 1951; Haas, 1953), whereas the so-called marine Middle Triassic beds of the Paraná basin (Reed, 1929) are now known to be continental Permian (Leanza, 1948; Camargo Mendes, 1952).

In western Argentina, the Lower Triassic is represented by a thick sandy-conglomeratic continental sequence exposed north of Mendoza city, bearing *Chiroterium* footprints in its lower part (Peabody, 1955; Stipanicic, 1957). In central Chile (upper Río Huasco), the Lower Triassic consists of rhyolitic flows and tuffs with intercalated conglomerates (Brüggen, 1950; Zeil and Ichikawa, 1958). In Middle Triassic time, the sea invaded the coastal strip of central Chile between Vallenar and Los Vilos where shallow-water deposits, bearing Anisian ammonites and pelecypods, were accumulated (Tavera in Muñoz Cristi, 1942; Zeil and Ichikawa, 1958; Barthel, 1958). Continental sedimentation persisted in the Precordillera of western Argentina.

In late Middle Triassic (Ladinian) time, intense volcanic activity sprouted in Chile between Calama and Langotoma (Muñoz Cristi, 1938, 1950; Harrington, 1961), the acidic and mesosilicic flows and tuffs spreading into western Argentina between La Rioja and Neuquén (Groeber, 1952). The extrusions rapidly decreased in the Early Norian, but in a few localities they persisted intermittently during the Late Norian and even during the earliest Liassic (Limón Verde area of northern Chile, Cordillera del Viento of western Argentina). The Middle Triassic volcanic cycle was also felt in southeastern Patagonia (Feruglio, 1949; Groeber, 1952; Stipanicic and Reig, 1955; Stipanicic, 1957) and in the Central Cordillera of Colombia between Chaparral and the Santa Marta Hills (Trumpy, 1943).

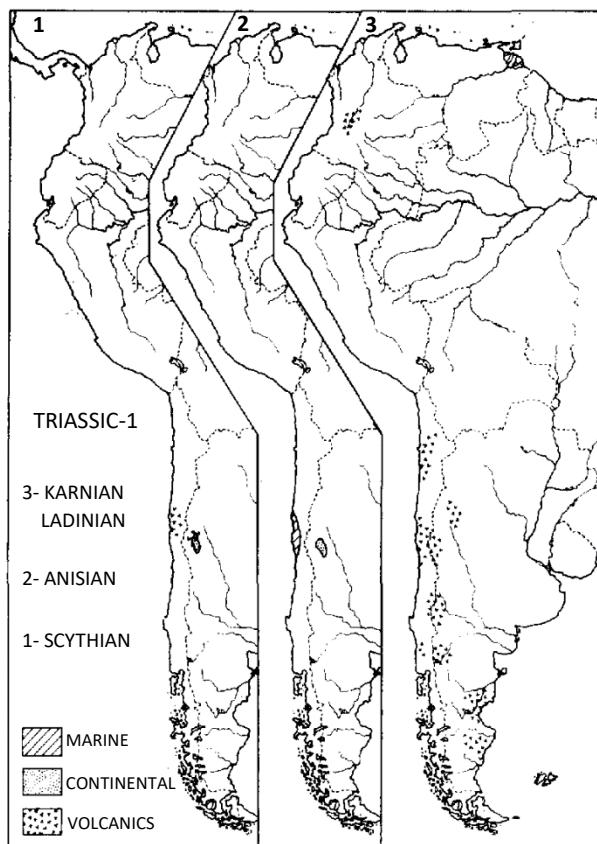


Fig. 16. – Paleogeographic maps of South America. Scythian to Karnian (Lower to Upper Triassic).

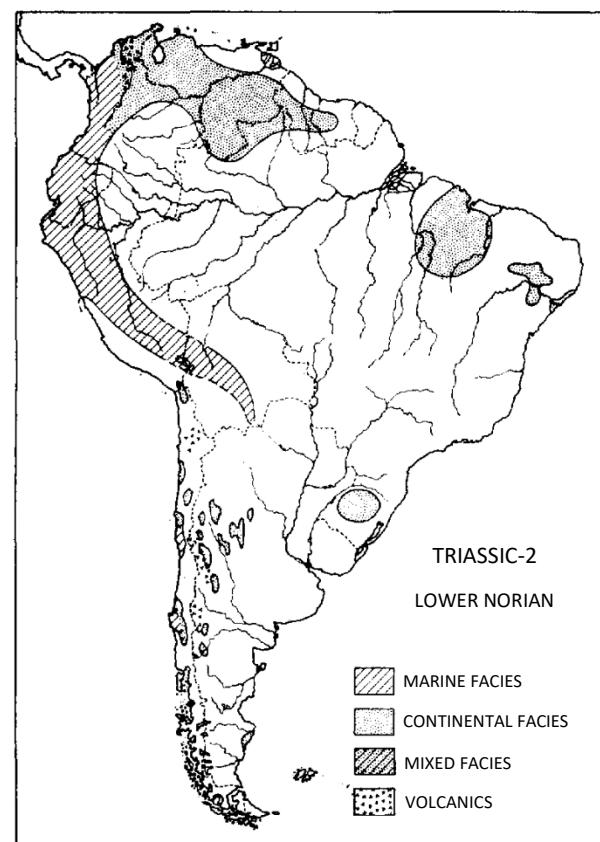


Fig. 17. – Paleogeographic map of South America. Lower Norian (Upper Triassic).

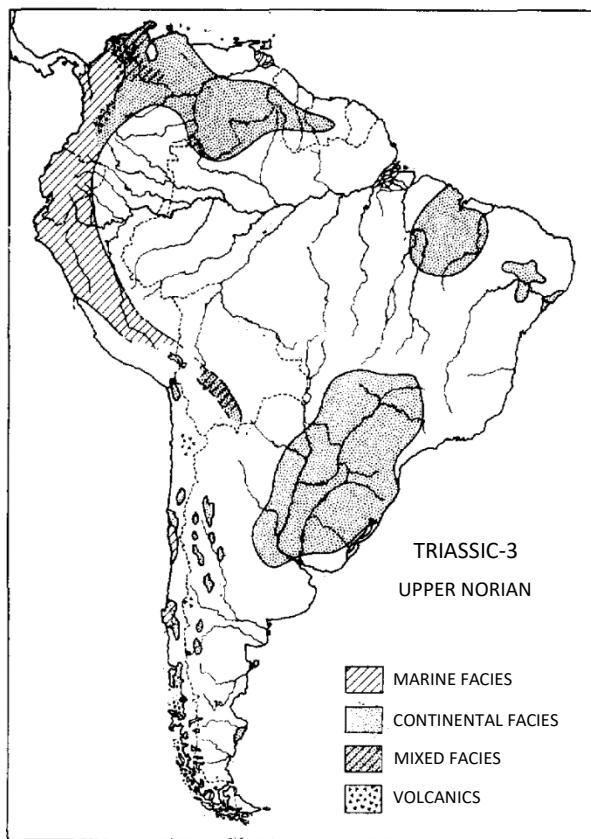


Fig. 18. – Paleogeographic map of South America. Upper Norian (Upper Triassic).

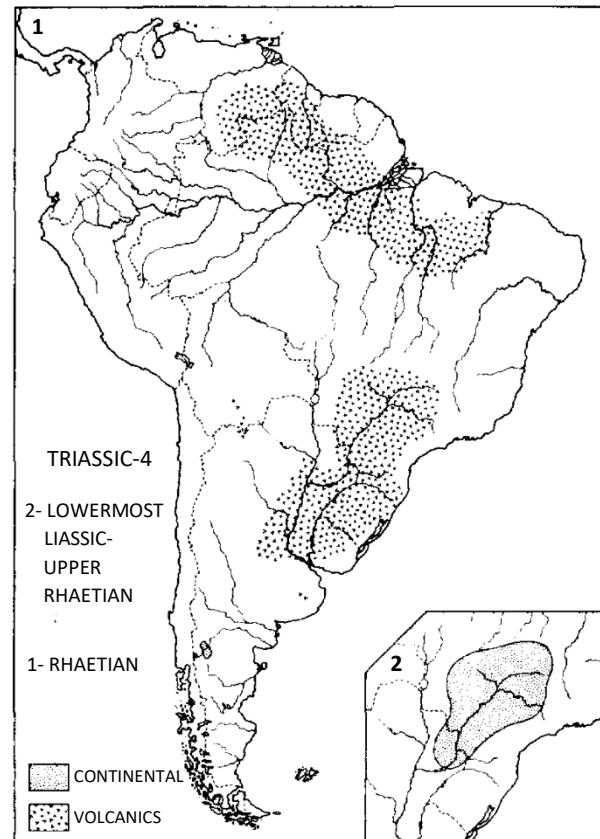


Fig. 19. – Paleogeographic maps of South America. Rhaetian to Lowermost Liasic (Upper Triassic to Lowermost Jurassic).

In the early Late Triassic (Early Norian), the sea invaded a long and narrow trough extending from central Colombia to southern Bolivia. In the main part of this basin, shallow marine beds bearing *Entomonotis ochotica* and *Myophorrigonia* were accumulated: they are now known in the Central Cordillera of Perú between Tarma and Utcubamba (Kummel, 1950; Jenks, 1951; Haas, 1953; Kummel and Fuchs, 1953), in the Western Cordillera of Perú east of Sechura (Olsson in Kummel, 1950), and in the Payandé district of the Central Cordillera of Colombia, where they overlie and underlie andesitic flows and tuffs with intercalated redbeds (Trumpy, 1943). East and north of the Payandé district, the Norian sequence grades into the continental Girón redbeds bearing estheriids and plant remains (Dickey, 1951; Trumpy, 1943). In the Cesar valley east of the Santa Marta Hills, the Norian seems represented by a thick group of redbeds with intercalated rhyolites and tuffs and estheriid-bearing shales (Trumpy, 1943). Farther north, in the Guajira peninsula, it seems represented by the dominantly continental Cojoro Formation (Renz, 1960), capped by rhyolitic tuffs and flows. In southwestern Venezuela, the Norian consists essentially of continental redbeds (La Quinta), bearing *Lepidotus* in the type locality (Kundig, 1938). Near Mucuchachí, however, these beds have yielded *?Halobia* and badly preserved ammonites (Kehrer, 1938), originally regarded as proceeding from the underlying Mucuchachí Formation. This, the fact that Trumpy (1943) mentioned "possible ammonite fragments" found near the top of the Cesar valley redbeds, and the presence of ostracods and pelecypods in the middle part of the Cojoro Formation (Renz, 1960), suggests that the Norian sea was able to encroach over northern Colombia and western Venezuela during a short-lived transgression. According to Hedberg (1942), continental beds comparable with the La Quinta Formation, are known in the subsurface of the Paraguaná peninsula and in southwestern Anzoategui and Guarico, south of the Caribbean Ranges of Venezuela (Hato Viejo and Carrizal).

In the southern extremity of the Colombian-Bolivian trough, the Norian is represented by the Cangapi-Vitiacua-Ipaguasu shallow marine to brackish-water sequence of the Subandean Ranges of southern Bolivia (Padula in Mauri et al., 1956; Padula and Reyes, 1958; Ahlfeld and Branisa, 1960). The Vitiacua limestones bear an Upper Triassic pollen assemblage in addition to pectinids and brachiopods of general Norian aspect.

During the Norian, volcanic activity rapidly decreased in the southern Andean belt and continental deposits accumulated in several places along the coastal strip of Chile between Arica and Nielol, with marine intercalations between Los Vilos and El Gomero (Fuenzalida, 1937; Muñoz Cristi, 1942, 1950; Felsch, 1921; Fritzsche, 1922). In western Argentina, continental deposits bearing a rich *Dicroidium* flora were accumulated in semi-isolated basins along the western Pampean Ranges (Lull, 1942; Frenguelli, 1944, 1948; Borrello, 1946; Stipanicic, 1957), the Precordillera (Stipanicic, 1941; Frenguelli, 1944, 1948; Groeber, 1952), southern Mendoza (Stipanicic, 1949, 1956), and Neuquén (Frenguelli, 1937, 1948). In all these localities the continental beds are intruded by basaltic sills. No marine Triassic deposits are known in Argentina: the beds described as such by Groeber (1924) from the Charahuilla district of Neuquén are now known to be Liassic (Lambert, 1946).

During Late Triassic time continental beds were extensively deposited in the extra-Andean regions. In the Early Norian, accumulation in the Paraná basin was restricted to its southern part, where the Santa María beds, bearing a rich reptilian fauna and a *Dicroidium* flora were deposited (Gordon and Brown, 1952; Martins et al., 1955). In Late Norian time, however, the whole Paraná basin was the site of eolian accumulation (Botucatú Formation) under desertic conditions (Almeida, 1952). Similar beds are known in the subsurface of the Santa Fe plains of Argentina (Groeber, 1952), whereas continental beds bearing a *Dicroidium* flora are exposed in northeastern Santa Cruz, Patagonia (Stipanicic, 1957). Continental beds (Pastos Bons) were also deposited in the Parnaíba basin (Campbell, 1950; Kegel, 1953; Link, 1959), where the lower beds contain *Lepidotus* and *Semionotus* (Santos, 1953) formerly regarded as Cretaceous (Roxo and Lofgren, 1934). In northeastern Brazil, a new sedimentary basin appeared in northern Baia, Sergipe, and Pernambuco, where the continental Cícero Dantas and Jatoba Formations were deposited (Barbosa, 1953). In the Guiana region, continental redbeds (Roraima Formation) were accumulated (Kugler, 1936; Aguerrevere et al., 1939; Hedberg, 1942), the sedimentary basin apparently extending across the Orinoco *llanos* into northwestern Venezuela.

During Rhaetian time, vast amounts of basaltic lavas (Serra Geral) were extruded in the Paraná basin, where they cover more than 380000 square miles with an average thickness of 2000 feet. The basalts are also known in the subsurface of the Argentine pampas. Similar extensive flows are known in the Parnaíba basin capping the Pastos Bons Formation (Campbell, 1950; Link, 1959), whereas numerous basic dikes and sills intrude the Paleozoic rocks of the Amazonas basin (Moura, 1938; Morales, 1959) and the Roraima redbeds of the Guianas (Choubert, 1954). Basaltic sills also intrude the Upper Triassic formations of southern Bolivia (Ahlfeld and Branisa, 1960).

The basaltic extrusions and intrusions ceased in Late Rhaetian or earliest Liassic time. The barren, continental Caiuá redbeds accumulated over the basaltic flows in the northern half of the Paraná basin (Penna Scorza, 1952; Maack, 1959), mark the last Lower Mesozoic sedimentary episode in this region. In western Argentina, the continental Paso Flores beds of Neuquén were deposited during Rhaetian time (Galli, 1953; Stipanicic, 1957).

3.9 Jurassic

3.9.1 Liassic — Liassic beds are extensively exposed along the western part of South America between Colombia and central Patagonia. They are absent in Venezuela, southern Colombia, and northern Ecuador, the coastal belt of Perú north of Paracas, and central Chile, which were persistently high areas during the whole of the Jurassic. Four basins, not directly connected with each other, can be recognized arranged *en échelon* between these positive elements: they may be termed the Colombian, Peruvian, Chilean, and Patagonian basins.

The Colombian and Peruvian basins were invaded by the sea early in the Liassic. Hettangian limestones bearing *Psiloceras planorbis* are known in the Central Cordillera of northern and central Perú (Tilmann, 1917; Harrison, 1943), whereas limestones with *Psiloceras* and *Arietites* form the base of a thick sequence of redbeds in the Central Cordillera of northern Colombia (Trumpp, 1943).

During Sinemurian time the sea was already regressing in the Colombian basin, as witnessed by the continental redbeds with intercalated acid flows and tuffs conformably succeeding the Hettangian limestones of the Central Cordillera (Trumpp, 1943). In the Peruvian basin, on the contrary, the sea advanced eastward and southward reaching the Oriente of Ecuador (Tschoopp, 1953), the middle Huallaga river (Rosenzweig, 1953), and the Huancavélica district (Jaworski, 1914), where it remained until the close of the Pliensbachian. In southeastern Ecuador, submarine volcanic activity was intense during this epoch (Tschoopp, 1953).

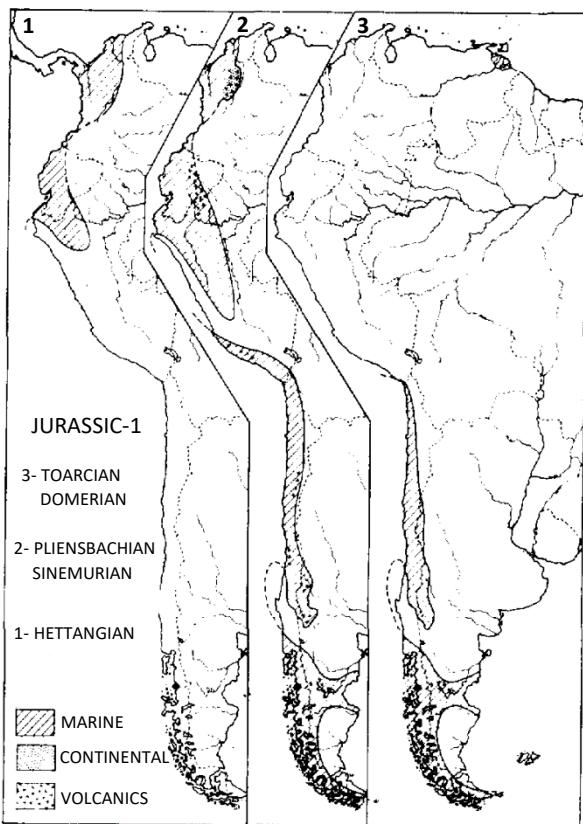


Fig. 20. – Paleogeographic maps of South America.
Liassic (Lower Jurassic).

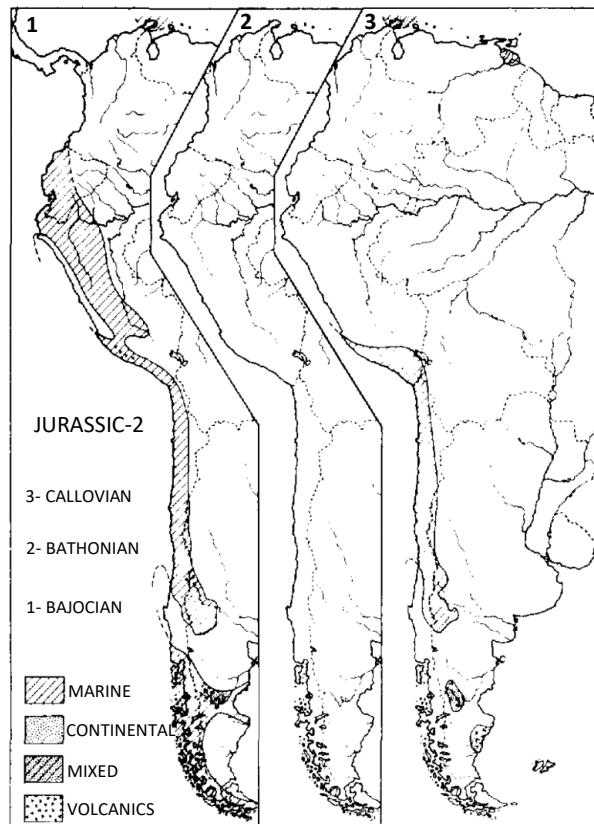


Fig. 21. – Paleogeographic maps of South America.
Dogger (Middle Jurassic).

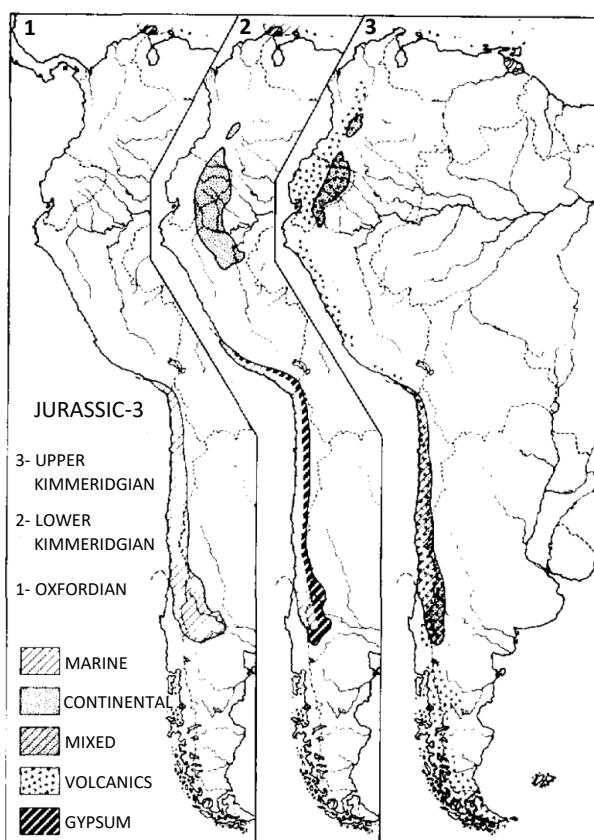


Fig. 22. – Paleogeographic maps of South America.
Lower and Middle Malm (Upper Jurassic)

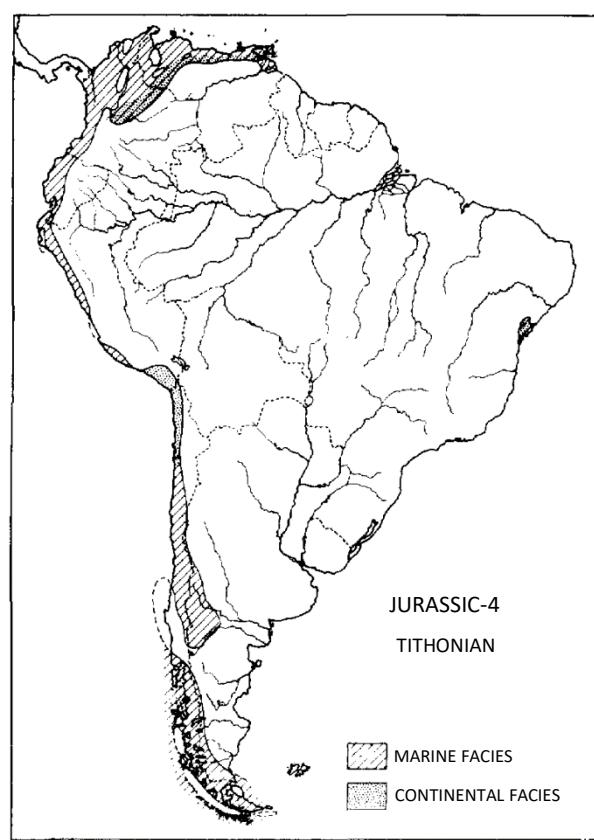


Fig. 23. – Paleogeographic maps of South America.
Tithonian (Upper Jurassic)

In Sinemurian to Lotharingian time, the sea invaded both the Chilean and the Patagonian basins. The transgression was preceded by mesosilicic volcanic activity that lingered until Pliensbachian time. Sinemurian to Pliensbachian beds are known near Arequipa in southwestern Perú (Jenks, 1948), and in several areas between northern Chile (Galli, 1957; Harrington, 1961) and Neuquén in western Argentina (Groeber, 1952). Beds of this age are also known in western Chubut (Feruglio, 1949; Groeber, 1952).

In Late Liassic time the sea abandoned the Colombian basin which disappeared as such, never to regain its negative character until the inception of the Tithonian. A similar general regression was felt in the Peruvian basin during the Late Liassic. The absence of Domerian and Toarcian beds in the Central Cordillera of Perú was explained by Groeber (1952) as due to pre-Tithonian erosion, but Weaver's (1942) idea of a general regression during Late Liassic time seems more likely as Bajocian beds are known in many localities between Cajamarca and Huancavélica. A partial regression was also felt along the northern extremity of the Chilean basin, whereas minor shifting of the coast lines occurred farther south. In the Patagonian basin, the Liassic sedimentary cycle continued without interruption from the Pliensbachian into the Toarcian. By the end of the Liassic, eruptions had ceased in the Chilean trough and they were weak and localized in the Patagonian basin (Feruglio, 1949; Groeber, 1952).

3.9.2 Dogger — The Peruvian basin was again invaded by the sea early in the Bajocian. The transgression flooded practically the same area which had been covered by the Liassic waters (Jaworski, 1914; Harrison, 1956) and extended farther south into the Andahuaylas and Cuzco provinces (Morales and Ocampo, 1956; Hoempler, 1957). In Bathonian time the sea abandoned the basin, which remained emergent until the Early Tithonian. Harrison's (1956) reference to doubtful Callovian ammonites south of Huancayo needs confirmation.

In the Chilean basin, sedimentation continued uninterruptedly from the Liassic into the Dogger. In Middle to Late Bajocian time, a slight advance of the sea was registered in southwestern Perú (Jenks, 1948; Rüegg, 1957) and eastern Neuquén (Groeber, 1952). Localized volcanic activity was felt in southwestern Perú and in southwestern Mendoza. During the Bathonian, a general regression was registered throughout the basin. No fossiliferous beds of this age are known either in the Argentine or Chilean sectors (Groeber, 1952; Cecioni and Garcia, 1960; Harrington, 1961). Biese's (1956, 1957) reports of fossiliferous Bathonian beds in northern Chile are very questionable and need confirmation. The Bathonian regression was succeeded by a readvance of the sea during Callovian time, especially marked in the northern extremity of the basin where the transgression reached the Titicaca Lake district (Jenks, 1948; Newell, 1949).

In the Patagonian basin, marine conditions persisted into the Early Bajocian, but by Late Bajocian time continental beds bearing dinosaur remains were being deposited in western Chubut (Cabrera, 1947; Groeber, 1952). Volcanic activity was weak and localized. During the Late Dogger, continental beds interbedded with tuffs accumulated both in western Chubut (Groeber, 1952) and eastern Santa Cruz (Stipanicic and Reig, 1955).

The northernmost tip of South America seems also to have been the site of intermittent deposition during the Dogger, as the sedimentary sequence displayed by the Cocinas Group of the Guajira peninsula (Renz, 1960) suggests a Bajocian transgression succeeded by a short-lived regression, and renewed deposition in Callovian time initiated with the accumulation of fluvial and deltaic conglomerates.

3.9.3 Lower and Middle Malm — The conglomerates of the upper Cocinas Group of the Guajira are succeeded by reefal limestones of probably Oxfordian age, the sequence ending with shales bearing Lower Kimmeridgian ammonites (Bürgl, 1958; Renz, 1960). Outside Chile and western Argentina, these are the only marine beds of Oxfordian-Kimmeridgian age known in South America.

Actually, of the four marine basins which appeared along the western belt of the continent in Early Liassic time, only the Chilean one persisted as such in the Late Jurassic. In Oxfordian time a partial regression was felt in its northern extremity, compensated by a slight advance of the sea in the Neuquén embayment. During the Early Kimmeridgian, thick beds of massive anhydrite associated with dolomites were accumulated all along the eastern border of the basin between Neuquén and southwestern Perú (Groeber, 1952; Corvalán Díaz, 1957; Rüegg, 1957; Cecioni and García, 1960; Harrington, 1961). It can be shown that the total amount of anhydrite accumulated in this belt exceeds the total amount of calcium sulphate dissolved at present in the oceans.

In the Oriente of Ecuador, redbeds with gypsum intercalations (Chapiza Formation) were accumulated in Early Kimmeridgian time (Tschopp, 1945, 1953) and similar beds (Sarayaquillo Formation) were deposited in northeastern Perú (Kummel, 1948) and in the middle Huallaga valley (Rosenzweig, 1953). They represent continental deposits accumulated along the eastern foot of a broad longitudinal swell seemingly uplifted as a result of gentle intra-Malm (Nevadian) movements on the site of the present Central Cordillera.

Nevadian movements are now known to have occurred in all western South American basins, but their effects are particularly evident in the Chilean trough, especially in southwestern Perú (Rüegg, 1957), northern Chile (Cecioni and García, 1960), and central Neuquén (Groeber, 1952). They began in Oxfordian time and continued intermittently until the close of the Kimmeridgian.

During Late Kimmeridgian time, volcanic activity was rampant in an unprecedented scale between central Colombia and Tierra del Fuego. The two main gaps in this almost continuous volcanic belt significantly coincide with the positive areas which separated the former Peruvian, Chilean, and Patagonian basins. In the Chilean basin vulcanism began with submarine eruptions located at some distance from the shore. Soon a garland of volcanic islands arose paralleling the coast of the trough and in the interior basin thus originated, shallow marine deposits accumulated together with vast amounts of pyroclastic materials (Groeber, 1952). Andesitic flows and tuffs of Late Kimmeridgian age, associated with continental beds, are also known in extra-Andean Patagonia (Feruglio, 1949). In the Oriente of Ecuador and in the Eastern Cordillera of southern Colombia, the Upper Kimmeridgian is represented by continental beds with abundant intercalations of flows and tuffs (Misahualli Formation) (Tschopp, 1953).

3.9.4 Upper Malm (Tithonian) — There is little doubt that if geology had been born in South America instead of Europe, the Jurassic-Cretaceous boundary would have been drawn between the Kimmeridgian and the Tithonian. The comparison of Figures 22, 23 and 24 is enough to show conclusively that the South American Tithonian is closely related to the succeeding Neocomian and completely divorced from the preceding Lower and Middle Malm. This fact has been long recognized by South American geologists and the name Mendocian (Groeber, 1952) is now widely used in Argentina and Chile for what was formerly called Tithonian-Neocomian.

Three marine basins appeared in Tithonian time along the western border of the continent: they may be termed the Venezuelan-Peruvian, Chilean, and Patagonian basins. All of them were invaded by the sea almost simultaneously, but the stage of maximum transgression was reached at different moments in the different basins.

In the Venezuelan-Peruvian basin, marine Tithonian beds are known in the Northern Range of Trinidad (Spath, 1939; Liddle, 1946; Kugler, 1956) and in the Caribbean Ranges near Caracas (Wolcott, 1943). The lower part of the continental to shallow marine Barranquín Formation of eastern Venezuela (Hedberg, 1950; Rod and Maync, 1954) and of the equivalent Río Negro Formation of western Venezuela (Sutton, 1946; Liddle, 1946) are almost certainly Tithonian. In the Eastern Cordillera of Colombia, Kehrer (1933) mentioned *Virgatosiphinctes* from near Gachalá, and Bürgl (1957) identified *Substeueroceras* cf. *lamellicostatus* and *Parodontoceras* aff. *callistoides* in the lower beds of the Cáqueza Formation of Cundinamarca. Tithonian ammonites were mentioned by Hubach and Alvarado (1945) from the eastern border of the Western Cordillera of Colombia near Cali. Marine Tithonian beds are known in isolated patches along the Western Cordillera of Perú between Chicama and Lima (Gerth, 1923; Lisson and Boit, 1942; Stappenbeck, 1942; Knetchel et al., 1947; Rivera, 1951; Bellido and Simons, 1957).

In the Chilean basin, marine Tithonian beds are known south of Nazca (Rüegg, 1957), east of Chañaral (Harrington, 1961), in the vicinity of Santiago (Corvalán Díaz, 1957), and in the Neuquén embayment (Groeber, 1952). In the Arequipa region of southwestern Perú and in the area between Arica and Iquique in northern Chile, the Tithonian is represented by continental beds (Jenks, 1948; Cecioni and Garcia, 1960).

In the Patagonian basin, marine Tithonian beds are known in several localities scattered between Lake San Martin (Feruglio, 1950) and Isla de los Estados (Harrington, 1943; Cecioni, 1957, 1958). The Tekenika beds of Hoste Island, bearing plant remains and marine fossils (Halle, 1913; Hoffstetter et al., 1957) are probably Tithonian. The Springhill Formation of the subsurface of the Chilean-Argentine oil fields of northern Tierra del Fuego and southern Santa Cruz, bearing *Otozamites* remains and marine fossils (Cecioni, 1955), is regarded by Cecioni as Tithonian but it might be younger.

In all three basins the negative movement responsible for the marine invasion was differential. Certain areas were rapidly downwarped whereas others, affected by a slower rate of subsidence, lagged behind to be finally engulfed by the sea as the transgression progressed during the Cretaceous. In the Venezuelan-Peruvian basin the Tinaco massif of eastern Cojedes (Renz and Short, 1960) remained emergent during the Tithonian, as well as the Avispas massif of the Venezuelan Andes (Young et al., 1956), the Santa Marta, Antioquia, Tolima, and Pasto massifs along the Central Cordillera of Colombia (Morales et al., 1958), the Amotape, Paita, and Illescas massifs of northwestern Perú (Fischer, 1956), the northern part of the Central Cordillera of Perú (Benavidez, 1956), and the off-shore belt between Illescas and Lima (Benavidez, 1956). In the Chilean basin, both the northernmost (Rüegg, 1957) and southernmost (Groeber, 1952) extremities remained emergent during the Tithonian, whereas in the Patagonian basin some tracts of the present Fueguian and Patagonian Cordilleras, as well as some areas along the northern extremity of the main island of Tierra del Fuego, progressively subsided during the Neocomian (Grossling, 1954; Cecioni, 1955).

In extra-Andean South America, the coastal strip of northeastern Brazil began to founder and the brackish-water lower beds of the Brotas Formation (Aliança Member), bearing ostracods of Purbeckian age (Sohn, 1942), were deposited in the Reconcavo basin (Link, 1959).

3.10 Cretaceous

3.10.1 Neocomian (Berriasian to Barremian) — In the northern section of the Venezuelan-Peruvian basin, the Neocomian beds succeeding the Tithonian are continental to shallow marine. Here belong the bulk of the Barranquín Formation of eastern Venezuela, the Riviere and Cumana Formations of Trinidad, and the Río Negro Formation of western Venezuela (Liddle, 1946; Wells, 1948; Barr, 1951; Kugler, 1956; Royo y Gómez, 1960). In the Eastern Cordillera of Colombia, the Neocomian is marine and represented by the Cáqueza and lower Villette Formations (Hubach, 1945, 1947; Bürgl, 1954, 1957), but in the Middle Magdalena valley it begins with continental beds (lower Tambor) succeeded by shallow marine deposits (upper Tambor and lower Basal limestones) (Morales et al., 1958). Farther south, in the Upper Magdalena valley, the Neocomian is absent. Little is known about the Central and Western Cordillera of Colombia, where the Cretaceous sequence is intruded by numerous andesitic sills and vast dioritic stocks of Late Senonian age. In the eastern flank of the Western Cordillera, however, Hubach and Alvarado (1945) reported Valanginian ammonites, whereas Grosse (1926) mentioned Barremian ammonites from the Antioquia district of the Central Cordillera. It seems certain that some sections along the site of the present Central Cordillera, particularly in Antioquia and southern Magdalena, and in southern Tolima, subsided more slowly than the rest and remained emergent during most of the Neocomian, to be finally covered by the sea in the Middle Cretaceous (Morales et al., 1958). The Amotape Mountains of northwestern Perú and their continuation into the Paita and Illescas regions, as well as the northern part of the Central Cordillera of Perú, also remained emergent during the Neocomian, to be finally covered by the sea in Albian time (Fischer, 1956; Benavidez, 1956).

Along the eastern half of the Ecuadorian and Peruvian sections of the Venezuelan-Peruvian basin, the Neocomian is represented by continental beds: the Hollín Formation of the Oriente of Ecuador (Tschopp, 1953), the Cushabatay Formation of the Contamana area of northeastern Perú (Kummel, 1948), the lower Agua Caliente sandstones of the middle Huallaga River (Rosenzweig, 1953; Moran and Fyfe, 1933), the Pongo sandstones of the Pongo de Manseriche and the Pachitea River (Singewald, 1926, 1927), the Yurinaqui sandstones of the Perené River (Chase, 1933), and the Moa sandstones of the Acre Territory east of the Ucayali River (Moura and Wanderley, 1938).

In the Western Cordillera of Perú, between Cajamarca and Huaraz, the Neocomian begins with continental beds (Chimú) succeeded in Late Valanginian time by marine beds (Santa) and these, in their turn, by shallow marine to continental deposits of Hauterivian-Barremian age (Carhuaz) (Tafur, 1950; Benavidez, 1956). The Neocomian is absent along the northern part of the Central Cordillera of Perú (Benavidez, 1956), but it is developed in a continental facies with marine intercalations between Cerro de Pasco and Junín (McLaughlin, 1924; Harrison, 1943, 1951, 1956). In the southern extremity of the basin, the Neocomian is represented by the shallow marine Muni and Huancané Formations of the Titicaca area (Heim, 1947; Newell, 1949; Groeber, 1952), by the Torotoro sandstones of the Central Cordilleras of Bolivia (Ahlfeld and Branisa, 1960), and by the lower part of the Areniscas Inferiores or Pirguá Formation of the Puna, Eastern Cordilleras, and Subandean Ranges of northern Argentina (Ruiz Huidobro, 1949; Vilela, 1951; Groeber, 1952).

In the northern extremity of the Chilean basin, the continental Tithonian Atajaña Formation is succeeded by marine Berriasian beds (Blanco Formation) (Cecioni and Garcia, 1960), but east of Antofagasta the Neocomian is continental (Harrington, 1961). Farther south, between central Chile and southern Neuquén, the Neocomian is dominantly marine (Groeber, 1952).

In the Patagonian basin, marine Neocomian sedimentites are widespread between western Chubut and Tierra del Fuego (Feruglio, 1950; Groeber, 1952; Cecioni, 1955).

Neocomian beds are extensively developed in the extra-Andean regions of northern South America. Along the coastal strip of northeastern Brazil, they are represented by the brackish-water Sergi and Japoatã Formations (Kellet Nadau, 1948; Taylor, 1952; Link, 1959). Farther west, the Neocomian is represented only by continental beds: these are the Corda and Codó Formations of the Parnaíba basin (Campbell, 1950; Link, 1959), the Sucundurí Formation of the Amazonas basin (Morales, 1959), and the Urucuia formation of the São Francisco basin (Oliveira and Leonardos, 1943). The Tombador and Caboclo Formations of the Salitre basin of northwestern Baia (Kegel and Pontes, 1957) are probably also of Neocomian age.

3.10.2 Aptian to Cenomanian — During Middle Cretaceous time a marked marine flooding was felt in the northern Andean basin where most of the intrabasinal massifs which had been slowly subsiding during the Neocomian were surrounded by the sea and finally engulfed in Albian time. Marine Aptian to Cenomanian beds are known in Trinidad (Toco, Sans Souci) (Kugler, 1956), eastern and western Venezuela (lower Temblador, upper Sucre, Cogollo) (Liddle, 1946; Hedberg, 1950; Kehrer, 1956; Young et al., 1956), the Eastern Cordillera of Colombia (upper Villeta) (Bürgl and Dumit Tobon, 1954; Bürgl, 1957; Hubach, 1957), and the middle and upper Magdalena valley (Tablazo, Simiti, Salto) (Morales et al., 1958). Information is scanty regarding the Central Cordillera of Colombia, but Grosse (1926) mentioned Aptian ammonites from the western border of the range in the Antioquía district. The marine advance was especially marked along the southern half of the Venezuelan-Peruvian basin, where the sea flooded the areas of eastern Ecuador and Perú which had been the site of continental accumulation during the Neocomian. Marine beds (Lower Napo) were deposited in the Oriente of Ecuador (Tschoopp, 1953) and in northeastern Perú (Middle Oriente) (Kummel, 1948). Marine limestones are widespread in the Central Cordillera of Perú as far south as Andahuaylas (McLaughlin, 1924; Harrison, 1943, 1951, 1956; Yates et al., 1951; Bellido, 1956; Morales and Ocampo, 1956). In the Western Cordillera of Perú, the Middle Cretaceous begins with continental beds (Goyllarisquizga) succeeded by Upper Albian and Lower Cenomanian marine deposits (Benavidez, 1956). Marine Middle Cretaceous beds (Pananga, Muerto) are also developed in northwestern Perú (Iddings in Olsson, 1928; Travis, 1953; Stainforth, 1955; Fischer, 1956). In the Lake Titicaca district, the Middle Cretaceous is represented by the shallow marine Moho shales bearing limestone intercalations in the lower part (Ayavacas) and near the top (Rassmuss, 1928; Cabrera La Rosa and Petersen, 1936; Heim, 1947; Newell, 1949). In the Central Cordilleras of Bolivia, the Middle Cretaceous is represented by the Suticollo Formation (Ahlfeld and Branisa, 1960) bearing limestone intercalations in the lower part (Miraflores) and near the top (Schlagintweit, 1941; Ahlfeld, 1959). Farther south, in the Puna, Eastern Cordilleras, and Subandean Ranges of northern Argentina, it is represented by the upper part of the Areniscas Inferiores, the Horizonte Calcáreo-Dolomítico (Yacoraite Formation), and the Margas Multicolores (Santa Bárbara Formation) (Ruiz Huidobro, 1949, 1958; Vilela, 1951; Groeber, 1952; Turner, 1959). The Calcáreo- Dolomítico and the limestone intercalations of the Suticollo Formation bear a rich marine to brackish- water fauna with abundant gastropods, regarded as Upper Triassic by Bonarelli (1921), Cossman (1925), and Haas (1953), but as Cretaceous by Fritzsche (1923), Steinmann (1930), Pilsbry (1939), Frenguelli (1937), Schlagintweit (1941), Groeber (1952), and Ahlfeld (1959).

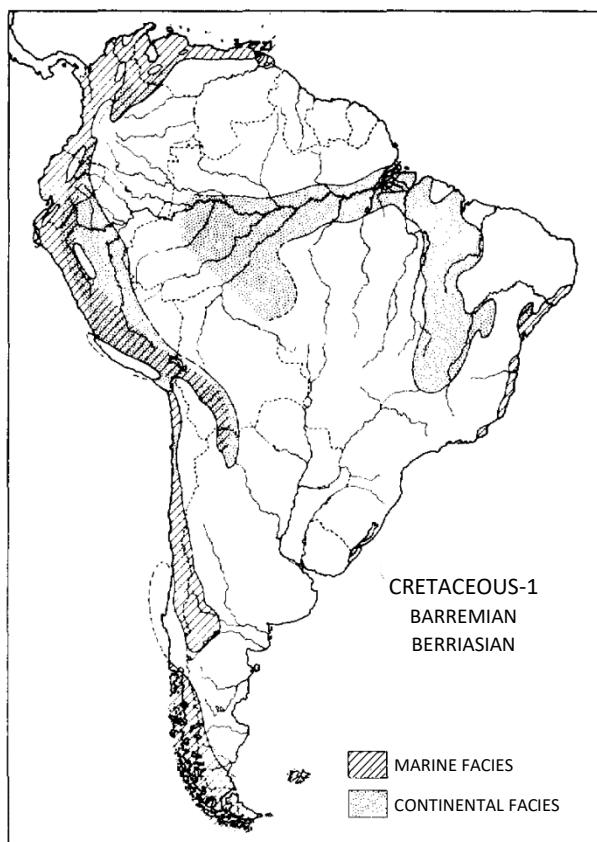


Fig. 24. – Paleogeographic map of South America.
Neocomian (Lower Cretaceous).



Fig. 25. – Paleogeographic map of South America.
Aptian to Cenomanian (Middle Cretaceous).



Fig. 26. – Paleogeographic map of South America.
Turonian to Coniacian (Upper Cretaceous).

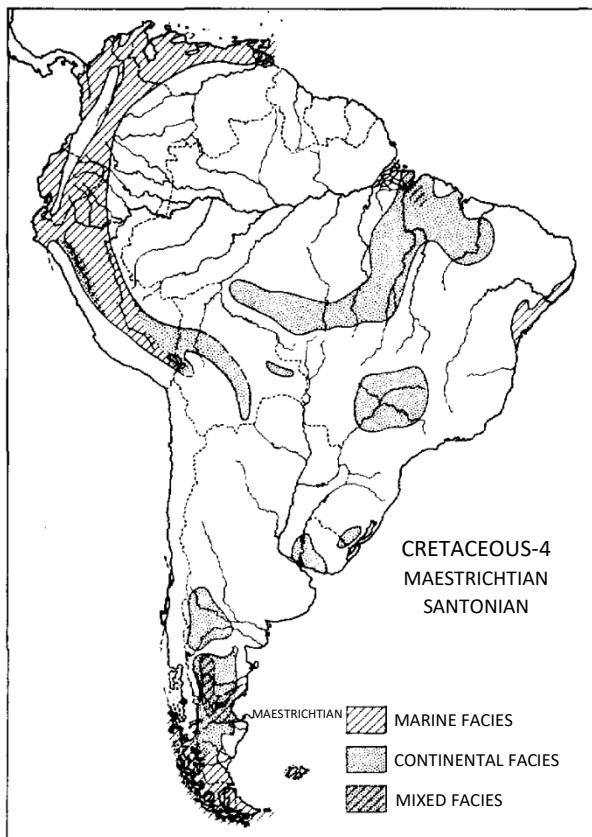


Fig. 27. – Paleogeographic map of South America.
Senonian (Upper Cretaceous).

During Middle Cretaceous time, a marine advance was registered in the northern half of the Chilean basin. Marine Aptian-Albian beds (Arcurquina limestones) are known in the Arequipa region of southwestern Perú (Jenks, 1948; Benavidez, 1956), whereas Albian limestones and shales (Way Formation) are exposed near Antofagasta in northern Chile (Leanza and Castellaro, 1955; Harrington, 1961). Similar beds have been described by Biese (1942) from central Chile. In the southern half of the basin a regression took place and subcontinental beds with evaporitic intercalations (Huitrín) were accumulated (Groeber, 1952).

In the Patagonian basin marine sedimentation continued uninterruptedly from the Neocomian into the Middle Cretaceous, the marine advance reaching maximum expansion during the Albian (Feruglio, 1950; Groeber, 1952). In contradistinction to conditions prevailing during the Neocomian, when the faunas of all three western basins were very similar, during Middle Cretaceous time the Patagonian fauna was sharply different from that of the Venezuelan-Peruvian trough.

In the extra-Andean regions, continental accumulation ceased in the intercratonic basins of Brazil, but in the coastal strip of northeastern Brazil marine and brackish-water sedimentation continued without interruption (Maury, 1936; Link, 1959).

3.10.3 Turonian and Coniacian — During this epoch, marine sedimentation continued in Venezuela (Upper Temblador, Querecual) and Colombia (Guadalupe), with euxinic conditions (La Luna) prevailing between western Venezuela and the upper Magdalena valley (Young et al., 1956; Bürgl, 1957; Morales et al., 1958), while intense volcanic activity was felt along the Central and Western Cordilleras of Colombia (Grosse, 1926; Hubach and Alvarado, 1945) and their southern continuation into Ecuador and northwestern Perú (Fischer, 1956). During Late Cenomanian time a partial regression was felt in the Ecuadorian-Peruvian section of the basin, followed in Turonian time by a readvance of the sea (Upper Napo-Chonta) which slightly exceeded that of the Albian (Tschopp, 1953; Kummel, 1948).

In the Chilean trough, the general regression initiated in the Middle Cretaceous led to the final withdrawal of the sea. Very intense volcanic activity was felt along western Chile from Arica to the Bio Bio, whereas continental beds accumulated on the Argentine section of the now almost obliterated basin (Groeber, 1952).

In the Patagonian basin a partial regression took place, but marine sedimentation continued along the site of the present cordilleras. In central and southern Patagonia, continental beds with some pyroclastic material of unknown source were deposited (Feruglio, 1950; Groeber, 1952).

In northeastern Brazil, the sea invaded the coastal areas of Río Grande do Norte and eastern Ceará (Sebastianópolis Formation) and of eastern Pernambuco (Beberibe Formation) (Maury, 1925; Beurlen, 1961).

3.10.4 Santonian to Maestrichtian — Sometime between the Middle Coniacian and the Early Santonian, tectonic movements affected the western belt of the continent and brought about the initial uplift of the Principal Cordillera of Argentina and Chile together with the Western and Central Cordilleras of Perú, the Cordillera Real of Ecuador, and the Central Cordillera of Colombia. These movements called “Peruvian” by Steinmann and “Subhercynian” by Stille, constitute the initial phase of the Andean diastrophic cycle which was responsible for the final shaping of the continent during Tertiary time.

As a result of the intra-Senonian differential uplift, the Venezuelan-Peruvian basin was longitudinally split into two subparallel troughs connected through gaps across the rising mesial mountains. The most notable of these gaps were located between the embryonic Caribbean Ranges and the Santa Marta hills, between these hills and the northern extremity of the Central Cordillera of Colombia, and between the Cordillera Real of Ecuador and the Western Central Cordilleras of Perú. The sea extended uninterruptedly along the narrow foredeep from eastern Venezuela through eastern Colombia, Ecuador, and Perú to the Titicaca Lake region. Here belong the Naparima Hill and Guayaguayare Formations of Trinidad (Kugler, 1956), the Santa Anita and Upper Temblador of eastern Venezuela (Young et al., 1956), the Colón of western Venezuela (Young et al., 1956), the Umir and Guaduas of the Magdalena valley and Eastern Cordillera of Colombia (Morales et al., 1958; Bürgl, 1957), the Callo and Guayaquil of western Ecuador (Marks, 1956; Marchant, 1956), the Upper Redondo of northwestern Perú (Travis, 1953), the lower Tena of the Oriente of Ecuador (Tschopp, 1953), the Vivian, Azúcar, and lowermost Capas Rojas of northeastern Perú (Kummel, 1948; Moran and Fyfe, 1933; Heim, 1947; Chase, 1933), and the Sipín of northwestern Titicaca (Heim, 1947; Newell, 1949). Continental beds, however (Chota), were accumulated along the eastern border of the Western Cordillera of northern Perú (Benavidez, 1956). From the region northeast of the Titicaca Lake across Bolivia to the boundary with Argentina, only continental beds were deposited. Here belong the Cotacucho-Vilquechico-Muñani sequence of the eastern Titicaca area (Newell, 1949), the Beu and Bala Formations of the northern Subandean Ranges of Bolivia (Reyes, 1959), and the Tacurú Formation of the southern Subandean Ranges (Padula in Mauri et al., 1956; Ahlfeld and Branisa, 1960).

The Chilean trough disappeared, folded, and uplifted into the Principal Cordillera, but a slight marine ingressions was registered in a few localities along the western foot of the rising mountains (Quiriquina Formation) (Muñoz Cristi, 1950, 1956).

In the Patagonian basin the intra-Senonian movements were intense in Dawson Island, where Lower Santonian conglomerates discordantly overlie Cenomanian shales (Cecioni, 1957), but elsewhere in Tierra del Fuego and in the Magallanes Province marine accumulation continued uninterruptedly until the end of the Cretaceous (Cecioni, 1957, 1957a; Hoffstetter, 1957).

In extra-Andean Patagonia, continental beds bearing dinosaur remains (Estratos con Dinosaurios, Chubutiano, Pehuenche) were accumulated (Herrero Ducloux, 1946; Feruglio, 1950; Groeber, 1952). In western Chubut and Santa Cruz they contain abundant pyroclastic material (Groeber, 1959). During Maestrichtian time, Atlantic waters invaded the sub-negative area interposed between the Patagonian and Deseado massifs, extending into western Chubut (Lefipán Formation) (Petersen, 1946; Feruglio, 1949).

Continental beds, bearing dinosaur remains, were deposited in southern Uruguay and conterminal areas of Argentina (Lambert, 1940). Farther north, the continental Baurú Formation was accumulated in the Paraná basin (Almeida, 1952). Continental beds were also extensively deposited in the Parnaíba basin (Campbell et al., 1949; Link, 1959), along the eastern and southern borders of the Central Brazilian shield (Oliveira and Leonardos, 1943), and in the Chiquitos region (Barbosa, 1946; Ahlfeld and Branisa, 1949). Sometime during the Senonian, the narrow Marajó-Belem trough began to subside at the mouth of the Amazonas and it was invaded by the sea (Oddone, 1953; Amaral, 1955; Morales, 1959). In northeastern Brazil, the sea abandoned Río Grande do Norte and eastern Ceará, whereas in the Baia-Sergipe basin, the Ilhas Formation and its equivalents were deposited under brackish-water conditions (Moura and Fernández, 1953; Taylor, 1952; Link, 1959).

3.11 Upper Cretaceous to Lower Tertiary

3.11.1 Danian-Paleocene — The boundary between Cretaceous and Tertiary is difficult to establish in South America owing to the uncertainty regarding the correct age assignment of some formations considered as either Danian or Paleocene, and to the sedimentary continuity between Cretaceous and Tertiary beds in some areas of dominantly continental accumulation.

During this interval, marine deposition persisted in the Venezuelan section of the northern Andean belt, but the Venezuelan Andes as well as parts of the Caribbean Ranges began to rise above sea-level (Liddle, 1946; Hedberg, 1950). In the central and southern sections of the basin, however, a marked regression was felt and the Colombian-Peruvian foredeep was abandoned by the sea. Here a great thickness of continental deposits began to accumulate east of the rising mountains: these are the Lisama Formation of Colombia, the upper Tena of Ecuador, the Cachiyacu of northeastern Perú, and the lower part of the Capas Rojas and Capas Morenas of eastern Perú, including the Huchpayacu, Huayabamba, lower Casapalca, lower Pocabamba, and lower Quincemil Formations (Morales et al., 1958; Tschopp, 1953; Kummel, 1948; Williams, 1949; Rosenzweig, 1953; Moran and Fyfe, 1933; Oppenheim, 1946). In western Ecuador and northwestern Perú, marine deposits were accumulated: these are the Santa Rosa, San Jose, and Estancia Formations of Ecuador, and the Balcones, Mesa, and upper Mal Paso of Perú (Thalmann, 1946; Travis, 1953; Stainforth, 1955; Marchant, 1956; Youngquist, 1958).

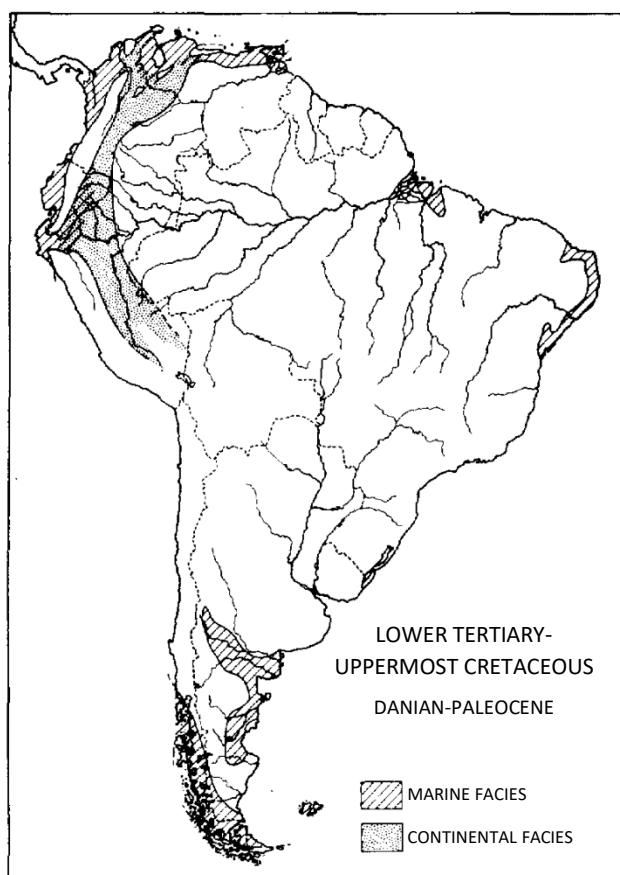


Fig. 28. – Paleogeographic map of South America.
Danian-Palaeocene (Lower Tertiary-Uppermost Cretaceous)

In the Patagonian basin, the sea became restricted to a narrow foredeep west of the rising Coast Cordillera, whereas in extra-Andean Patagonia the continental Senonian was succeeded by a Danian transgression proceeding from the Atlantic Ocean which flooded the subnegative areas between the Deseado, Patagonian, and Pampean Ranges massifs and reached southern Mendoza (Salamanca and Roca Formations) (Feruglio, 1950; Groeber, 1952, 1956).

In the Reconcavo basin of northeastern Baia, the São Sebastião marine to brackish-water beds were deposited in direct continuity over the Ilhas Formation, whereas farther north the sea encroached over Río Grande do Norte and Ceará (Maury, 1925). Continental accumulation ceased in the interior of Brazil, but marine sedimentation persisted in the Marajó-Belem trough (Oddone, 1953).

3.12 Tertiary

3.12.1 Eocene-lower Oligocene — During Eocene time the general features of the northern Andean basins remained little altered even if the northern extremity of the Eastern Cordillera of Colombia began to be uplifted together with the Perijá Range, parts of the Caribbean Ranges, and the Northern Range of Trinidad. In western Colombia and Ecuador, however, important changes were introduced in Eocene time by the opening of the so-called “Bolívar geosyncline” (Schuchert, 1935), interposed between the rising cordilleras and the Malpelo land mass now subsided below the Pacific waters (Nygren, 1950). Farther south, the Azúcar, Socorro, and Ancón Formations of southwestern Ecuador, and the Negritos, Lobitos, Talara, and Chira Groups of northwestern Perú were accumulated (Marchant, 1956; Travis, 1953; Bellido and Simons, 1957).

In the long Colombian-Peruvian foredeep thick continental beds were deposited, mainly derived from the erosion of the rising mountains to the west. Here belong the Chorro Group of Colombia (Morales et al., 1958), the Tiyuyacu-Chalcana Formations of Ecuador (Tschopp, 1953), and the middle part of the Capas Rojas, Contamana, and Quincemil Formations, and the bulk of the Pocabamba and Casapalca Groups of Perú (Bellido and Simons, 1957). In Early Oligocene time the sea advanced through the Ecuadorian portal and reached the Oriente of Ecuador and northeastern Perú where shallow marine to brackish-water beds (Pozo Formation) were intercalated in the dominantly continental sequence (Williams, 1949; Koch, 1959). In the region now occupied by the Altiplano of southern Perú and western Bolivia the thick continental Puno and Corocoro beds began to accumulate along the eastern foot of the rising Principal Cordillera (Newell, 1949; Ahlfeld and Branisa, 1960). The continental Huanca Formation of the Arequipa district of southwestern Perú (Jenks, 1948) is probably contemporaneous. In the Paracas-Ica region the sea was able to encroach over the western foot of the rising mountains (Petersen, 1954; Newell, 1956; Rüegg, 1957).

In the Patagonian basin, restricted to a narrow foredeep east of the rising Coast Cordillera, marine conditions persisted until the middle Oligocene (Concepción, Boquerón, Agua Fresca, Loreto, Magallanian beds) (Keidel and Hemmer, 1931; Feruglio, 1950; Todd and Kniker, 1952; Grossling, 1954; Muñoz Cristi, 1956; Hoffstetter, 1957).

In early Eocene time, volcanic activity was felt in western Chubut. As the activity decreased it was succeeded by a cycle of continental sedimentation which began in middle Eocene time and ended at the close of the lower Oligocene. As a result, continental tuffites bearing a rich mammalian fauna were accumulated in extra-Andean Patagonia and in the region between eastern Neuquén and southwestern Mendoza (Simpson, 1941, 1948; Feruglio, 1949; Herrero Ducloux, 1946; Groeber, 1952).

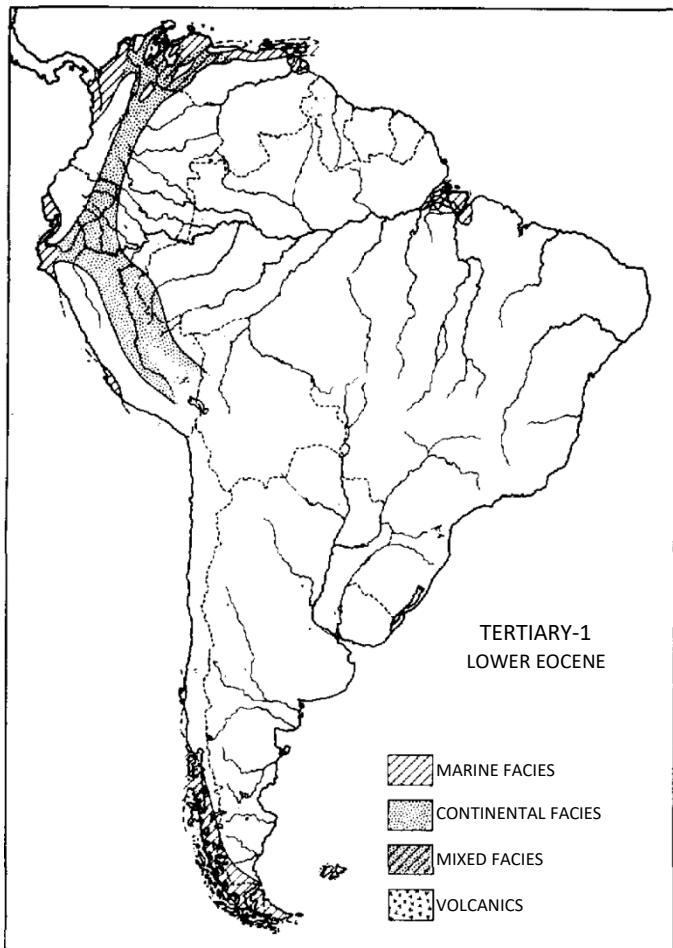


Fig. 29. – Paleogeographic map of South America.
Lower Eocene (Lower Tertiary).

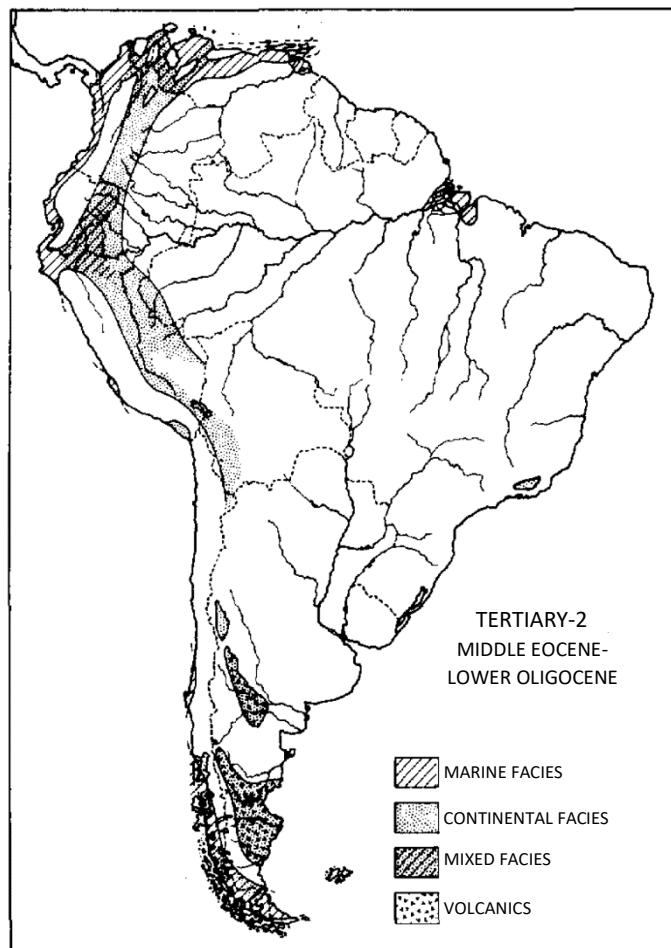


Fig. 30. – Paleogeographic map of South America.
Middle Eocene to lower Oligocene (Lower to Middle
Tertiary).

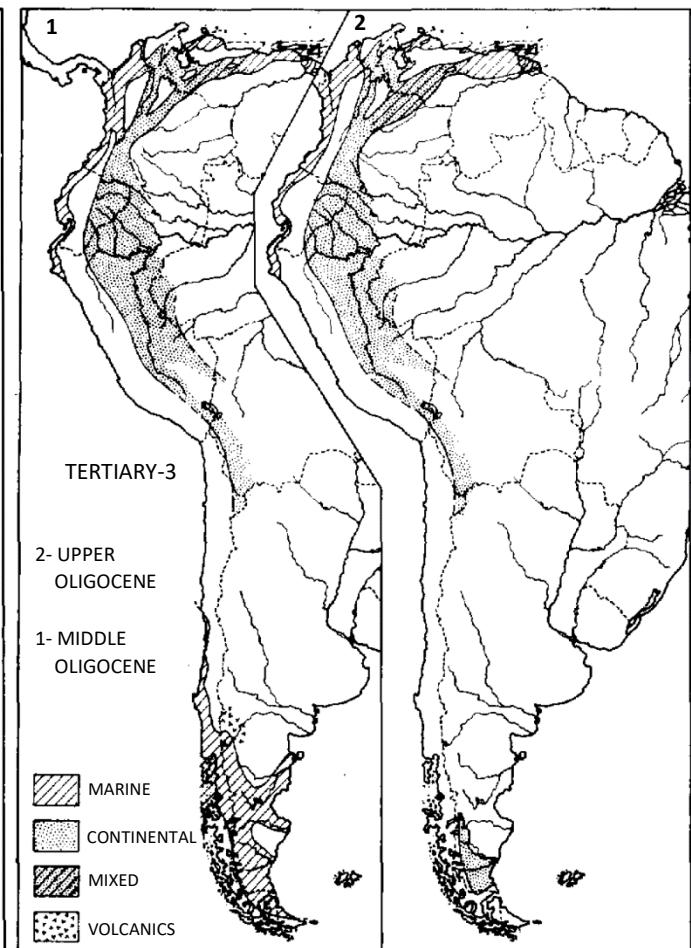


Fig. 31. – Paleogeographic maps of South America.
Middle and Upper Oligocene (Middle Tertiary).

Continental beds, bearing upper Eocene-lower Oligocene mammals, were also deposited in the small Itaboraí basin of eastern Brazil (Couto, 1952), whereas farther north marine sedimentation persisted in the Marajó-Belem trough (Oddone, 1953).

3.12.2 Middle and upper Oligocene — At the close of the lower Oligocene, renewed orogenic movements were felt almost throughout the continent. The Caribbean-Venezuelan mountains were bodily uplifted and the northern basins became the site of shallow marine deposition, alternating with brackish-water and continental sedimentation. The Bolívar geosyncline, however, was in full subsidence and great thicknesses of marine deposits were accumulated throughout the narrow seaway. The Ecuadorian “sea portal” was finally closed and the Colombian-Peruvian foredeep lost its precarious connection with the Pacific waters, receiving only continental sediments (Chuspas of Colombia, Chalcaña of Ecuador, upper Contamana, upper Capas Rojas, and upper Quincemil of Perú). In the Altiplano of southern Perú and western Bolivia, continental accumulation persisted as the Principal Cordillera was further uplifted.

In the Patagonian basin, the Patagonian Cordillera was uplifted together with the Coast Cordillera at the close of the lower Oligocene. These movements were attended by volcanic activity in southeastern Neuquén. In middle Oligocene time, Atlantic waters flooded the subnegative areas of Santa Cruz and Chubut. One or more gaps across the rising western mountains enabled the Atlantic transgressing sea to communicate with the Pacific waters, as witnessed by the close faunal similarity between the Patagonian Formation of Argentina and the Navidad Formation of west-central Chile (Feruglio, 1950; Brüggen, 1950; Camacho and Fernández, 1956).

At the close of the middle Oligocene, the Patagonian-Coast Cordilleras were further uplifted and the sea finally withdrew from the Patagonian basin. During late Oligocene time continental sediments and tuffs were accumulated in extra- Andean Patagonia (Feruglio, 1950).

3.12.3 Lower Miocene — In Early Miocene time, the Eastern Cordillera of Colombia, which had been rising slowly since the early Tertiary, suffered its first strong uplift. Sedimentary conditions, however, remained essentially unaltered in the Venezuelan troughs, the Bolívar geosyncline, and the Colombian-Peruvian foredeep. Continental accumulation also persisted in the Altiplano of western Bolivia, but farther east the Central and Eastern Cordilleras began to be uplifted. As a result, a fanglomeratic apron (Petaca, Areniscas Superiores) began to spread over the region now forming the Subandean Ranges and the western Chaco plains (Mauri, 1956; Ahlfeld and Branisa, 1960).

In the southern part of the continent, volcanic activity was felt in western Neuquén and Chubut.

In northern Brazil, the sea invaded part of the Parnaíba basin, which communicated with the Marajó-Belem trough. Here the Pirabás and Salinas marine beds were accumulated (Maury, 1925; Oddone, 1953; Morales, 1959; Link, 1959).

3.12.4 Middle Miocene — During Middle Miocene time the northern sedimentary basins suffered further reduction with the progressive rising of the Eastern Cordillera of Colombia. At the same time, the rate of subsidence of the Bolívar geosyncline rapidly decreased and though marine deposits were still accumulated in its northern and southern extremities, brackish-water beds were laid down along its central part (Nygren, 1950).

In Bolivia and northern Argentina continental accumulation persisted in the Altiplano and along the eastern foot of the Eastern Cordilleras. Farther south, continental beds with pyroclastic material were deposited along the foot of the Principal and Patagonian Cordilleras in southern Mendoza and western Patagonia (Groeber, 1946).

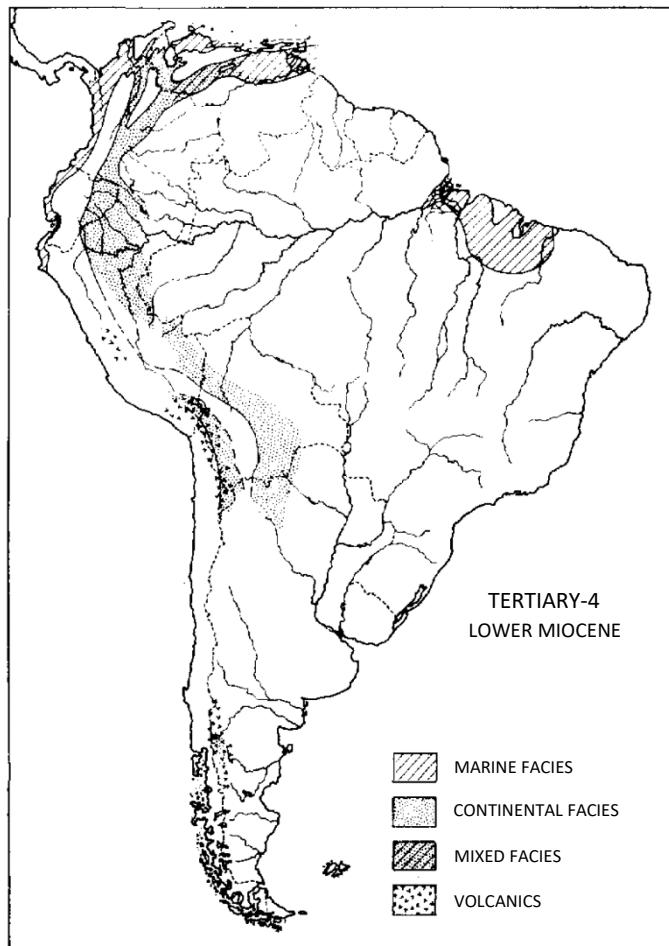


Fig. 32. – Paleogeographic map of South America.
Lower Miocene (Upper Tertiary).

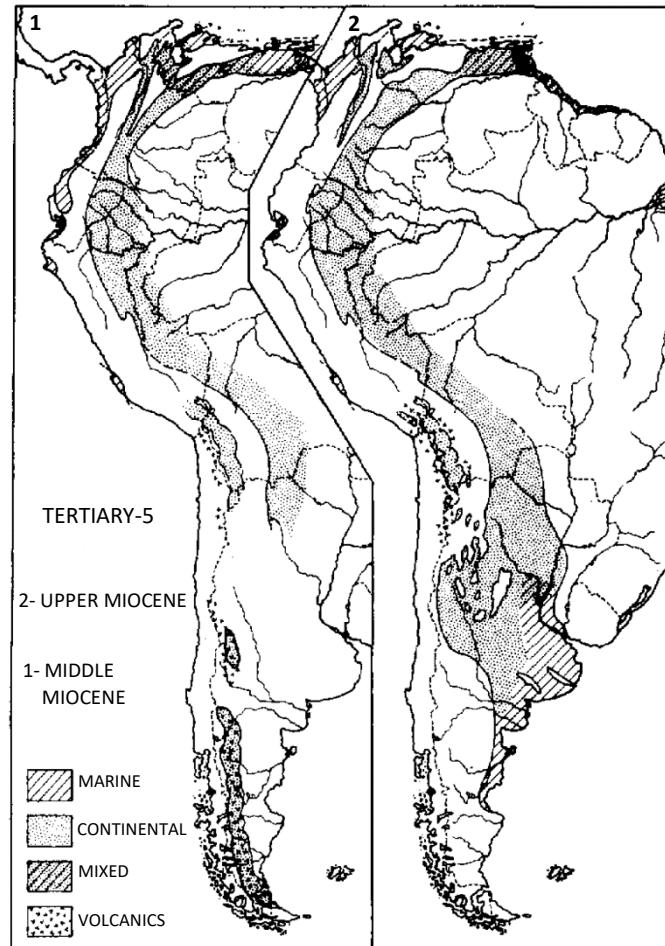


Fig. 33. – Paleogeographic maps of South America.
Middle and upper Miocene (Upper Tertiary).

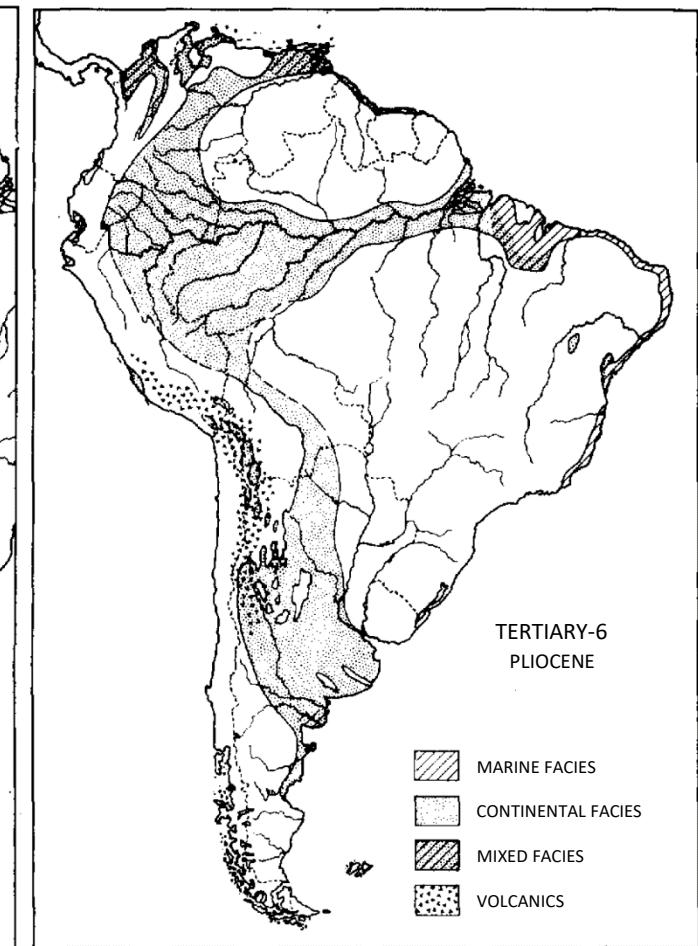


Fig. 34. – Paleogeographic map of South America.
Pliocene (Upper Tertiary).

3.12.5 Upper Miocene — Further uplift of the Eastern Cordillera of Colombia and of the Venezuelan ranges brought about the separation of the Llanos basin from the peripheral troughs. The Bolívar geosyncline began to rise above sea-level and brackish-water to continental beds accumulated in its middle part.

In the southern half of the continent, the Puna and Pampean Ranges began to be differentially uplifted, while volcanic activity was felt in the Western Cordillera of Bolivia and Perú and in the Chilean-Argentine Puna. In the structural valleys interposed between the rising mountain blocks, continental deposits (Calchaquí) were accumulated, merging northward with the fanglomeratic apron spreading east of the Eastern Cordillera (Terciario Subandino, Chaco). At the same time an Atlantic transgression flooded eastern Argentina from the lower Paraná River to the San Jorge gulf.

3.12.6 Pliocene — During Pliocene time the Bolívar geosyncline was finally uplifted above sea-level and continental deposits accumulated in the vanishing trough (Nygren, 1950). Marine conditions persist only between the lower Atrato and the lower Magdalena Rivers. Farther east, mixed continental and marine facies were developed in the Falcon and lower Orinoco areas of Venezuela, and along the coastal belt of the Guianas (Choubert, 1954). The sea invaded a narrow strip along the eastern and northeastern coasts of Brazil and flooded once again part of the Parnaíba basin. Farther west, extensive continental deposits were accumulated in the Amazonas basin. Part of these beds, however (Pebas Formation), might be of Miocene or even older age.

Continental accumulation persisted all along the eastern foot of the Cordilleras from Colombia through Ecuador, Perú, and Bolivia into Argentina. At the same time, acid and mesosilicic volcanic activity was rampant between southwestern Perú and northwestern Argentina. In the last named country, continental accumulation closely followed the pattern set up during Late Miocene time and great thicknesses of fanglomeratic beds were deposited in the structural depressions interposed between the rising Pampean Ranges and Puna blocks. At the close of the Miocene, the sea abandoned eastern Argentina.

The last major tectonic events took place at the close of the Pliocene, with the uplift of the Precordillera of western Argentina, the Subandean Ranges of northern Argentina and Bolivia, and the upthrow of the eastern border of the Cordillera Real of Ecuador.

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